AF

Atty. Dkt. No. 023971-0371

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant:	Junpei OGAWA et al.
Title:	HIGH-STRENGTH CONNECTING ROD AND METHOD OF PRODUCING SAME
Appl. No.:	10/771,522
Filing Date:	02/05/2004
Examiner:	Vinh LUONG
Art Unit:	3682
Confirmation No:	3059

TRANSMITTAL OF RESPONSE TO NOTICE OF NON-COMPLIANT BRIEF ON APPEAL

Mail Stop Appeal Brief - Patents
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

Attached is a Response to the Notice of Non-Compliant Brief on Appeal mailed from the U.S. Patent Office on July 20, 2006, presenting a Revised Brief on Appeal.

The Commissioner is hereby authorized to charge any additional fees which may be required regarding this application under 37 C.F.R. §§ 1.16-1.17, or credit any overpayment, to Deposit Account No. 19-0741. Should no proper payment be enclosed herewith, as by the credit card payment form being unsigned, providing incorrect information resulting in a rejected credit card transaction, or even entirely missing, the Commissioner is authorized to charge the unpaid amount to Deposit Account No. 19-0741.

If any extensions of time are needed for timely acceptance of papers submitted herewith, applicant hereby petitions for such extension under 37 C.F.R. §1.136 and authorizes payment of any such extensions fees to Deposit Account No. 19-0741.

Please direct all correspondence to the undersigned attorney or agent at the address indicated below.

Respectfully submitted,

Date Aug 21, 2006

By

FOLEY & LARDNER LLP
Customer Number: 22428
Telephone: (202) 295-4747
Facsimile: (202) 672-5399

Martin J. Cosenza
Attorney for Applicant
Registration No. 48,892

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Appl. No. 10/771,522
Atty. Dkt. No. 023971-0371

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
BEFORE THE BOARD OF PATENT APPEALS AND INTERFERENCES

Appellants: Junpei OGAWA et al.

Title: HIGH-STRENGTH CONNECTING ROD AND METHOD OF PRODUCING SAME

Appl. No.: 10/771,522

Filing Date: 02/05/2004

Examiner: Vinh LUONG

Art Unit: 3682

RESPONSE TO NOTICE OF NON-COMPLIANT BRIEF ON APPEAL

Mail Stop Appeal Brief - Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

This is in response to the Notice of Non-Compliant Appeal Brief mailed from the U.S. Patent Office on July 20, 2006.

1) Attached please find a Revised Brief on Appeal.

2) Statements regarding the status of each amendment to the application after final rejection (with regard to box "3" of the Notice) are provided **on page 5** of the Revised Brief on Appeal.

3) A concise statement of each ground of rejection (with regard to box "5" of the Notice) is presented **on page 9** of the Revised Brief on Appeal.

4) A correct copy of the appealed claims as an appendix thereto (with regard to box "7" of the Notice) is provided in "Claims Appendix" spanning pages 36-39 of the Revised Brief on Appeal.

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5) The former "Exhibit Appendix II" (with regard to box "8" of the Notice) is no longer present in the Revised Brief on Appeal, and thus the publication "Review of the Performance of High Strength Steels Used Offshore," is not in the Revised Brief on Appeal.

The Commissioner is hereby authorized to charge any additional fees which may be required regarding this application under 37 C.F.R. §§ 1.16-1.17, or credit any overpayment, to Deposit Account No. 19-0741. Should no proper payment be enclosed herewith, as by the credit card payment form being unsigned, providing incorrect information resulting in a rejected credit card transaction, or even entirely missing, the Commissioner is authorized to charge the unpaid amount to Deposit Account No. 19-0741.

If any extensions of time are needed for timely acceptance of papers submitted herewith, applicant hereby petitions for such extension under 37 C.F.R. §1.136 and authorizes payment of any such extensions fees to Deposit Account No. 19-0741.

Please direct all correspondence to the undersigned attorney or agent at the address indicated below.

Respectfully submitted,

Date Apr 21, 2006

By

FOLEY & LARDNER LLP
Customer Number: 22428
Telephone: (202) 295-4747
Facsimile: (202) 672-5399

Martin J. Cosenza
Attorney for Applicant
Registration No. 48,892

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
BEFORE THE BOARD OF PATENT APPEALS AND INTERFERENCES

Appellants: Junpei OGAWA et al.

Title: HIGH-STRENGTH CONNECTING ROD AND METHOD OF PRODUCING SAME

Appl. No.: 10/771,522

Filing Date: 02/05/2004

Examiner: Vinh LUONG

Art Unit: 3682

REVISED BRIEF ON APPEAL

Mail Stop Appeal Brief - Patents
P.O. Box 1450
Alexandria, VA 22313-1450

REAL PARTY IN INTEREST

The real party in interest is Nissan Motor Co., LTD.

RELATED APPEALS AND INTERFERENCES

There are no related appeals and interferences.

STATUS OF CLAIMS

The following constitutes a statement of the status of all the claims, wherein all claims currently rejected (claims 1, 2, 4, 19 and 21-25) are hereby appealed:

1.	Rejected
2.	Rejected
3.	Objected To
4.	Rejected
5 – 18.	Withdrawn
19.	Rejected
20.	Allowed
21 – 25.	Rejected
26 – 28.	Withdrawn

STATUS OF AMENDMENTS

1) ***There are no claim amendments that have not been entered.***

2) ***There is only one specification amendment that has not been entered.*** This is proffered amendment to the paragraph starting on line 6 of page 24 of the specification. The proffered amendment is presented in bold highlighting below.

The high-strength connecting rod of this invention is a connecting rod so shaped as to have a connecting beam section, a big end, a small end and a joining section as stated above. The connecting rod has a portion of the smallest cross sectional area in its connecting beam section, a portion of the lowest fatigue strength at its big or small end, and a portion of varying fatigue strength in its joining and connecting beam sections. **<u>In another embodiment, a portion which is the lowest in fatigue strength exists in at least one of the big and small ends, and a portion which varies in fatigue strength exists in each of the first and second joining sections and in the connecting beam sections.</u>** The connecting rod is so made that the product of its cross sectional area and fatigue strength at cross section of its joining and connecting beam sections may be equal to or greater than the product of its cross sectional area and fatigue strength in its portion of the smallest cross sectional area in its connecting beam section. The connecting rod contains 0.73% or less of C on a mass basis (i.e., % by weight) and is so made that the cross section of each of its connecting beam and joining sections may be composed of a tempered martensitic structure or a ferritic-pearlitic structure, or a mixture of these structures satisfying relational expression or Eq. (1) given above. At least the entire cross section of its portion of the smallest cross sectional area in its connecting beam section may be of a tempered martensitic structure. Therefore, it is possible to achieve a reduction of residual stress in its fully hardened portion and its boundary of hardening, an improvement in the fatigue strength of the connecting rod and a reduction in the weight of the part.

SUMMARY OF CLAIMED SUBJECT MATTER

Claim 1: Claim 1 recites a connecting rod which may be used, for example, to connect a crank shaft to a piston in an internal combustion engine. Referring to Figs. 1 and 2, and the specification, for example, at page 9, line 19 to page 11, line 21, the connecting rod 10 includes a connecting beam section / main body 40, a big end 20 axially opposite a small end 60, a first joining section 30 located between the connecting beam section 40 and the big end 20 to connect the beam section 40 and the big end 20, and a second joining section 50 located between the connecting beam section 40 and the small end 60 to connect the beam section 40 and the small end 60. As may be seen from Figs. 1 to 6, each of the first and second joining sections (30, 50) gradually and continuously decreases in cross sectional area toward the connecting beam section (40).

Claim 1 further recites that "each of the first and second ***joining sections . . . has a strength distribution in which a strength increases with a decrease in the cross sectional area.***" (Emphasis added.) That is, as opposed to a prior art connecting rod where strength ***decreases*** with a ***decrease*** in cross sectional area, the connecting rod has a strength distribution that changes in an ***opposite*** manner. Fig. 7, in view of Fig. 1, graphically illustrates this feature of claim 1, as is detailed on page 11, lines 22 to page 12, line 16 of the specification. This feature imparts the advantage of providing a connecting rod that is easily machined in the areas where machining must take place (*e.g.,* at/near the big and small ends which rotationally connect to the crank shaft and piston respectively), due to the relatively low strength in these locations, and a rod that has relatively high strength in locations that do not need to be machined, which correspond to sections of relatively lower cross sectional area. The connecting rod is easily machined in these areas because the hardness of the material is low. This invention provides the "best of both worlds": ease of machineability in areas which must be machined, and high strength in areas that need not be machined.

Claim 2: Claim 2 recites a connecting rod as claimed in claim 1, wherein the strength distribution is based on a proportion (%) of martensite. Fig. 9 presents a graphic

depiction of the change in the proportion of martensite with respect to location on the connecting rod (as well as depicting the cross sectional area of the rod with respect to location on the connecting rod). The specification, from page 12, line 21 to page 14, line 8, for example, details the features of claim 2.

Claim 3: Claim 3, which is allowed, recites a connecting rod as claimed in Claim 2, wherein the proportion of martensite (%) changes based on a change of the cross sectional area of each of the first and second joining sections in a manner to satisfy a relationship represented by the following formula:

$$D/D_{min} \geq 1/((1-\alpha) \times Ms/100 + \alpha)$$

where D_{min} is the minimum value of the cross sectional area of each of the first and second joining sections; and α is a value obtained by dividing a buckling stress without hardening by a buckling stress with hardening. The specification, from page 12, line 31, to page 13, line 11, for example, details the features of claim 3.

Claim 4: Claim 4 recites a connecting rod as claimed in claim 2, wherein the strength distribution is formed based on a distribution in at least one of a hardening temperature and a tempering time for each of the first and second joining sections. The specification details this feature, for example, from page 12, line 21, to page 15, line 31.

Claim 19: Claim 19 recites a novel connecting rod which also may be used, for example, to connect a crank shaft to a piston in an internal combustion engine. Referring to Figs. 1 and 2, and the specification at page 9, line 19 to page 10, line 32, page 21, line 27 to page 25, line 2 and the example on page 32, line 4 to page 33, line 15, the connecting rod 10 includes a connecting beam section / main body 40, as is detailed in claim 1, with the further feature that the connecting beam section has "a smallest cross sectional area portion which is the smallest in cross sectional area throughout the connecting rod." As with claim 1, the connecting rod also has a big end 20 axially opposite a small end 60, a first joining section 30 located between the connecting beam section 40 and the big end 20 to connect the beam

section 40 and the big end 20, and a second joining section 50 located between the connecting beam section 40 and the small end 60 to connect the beam section 40 and the small end 60. As may be seen from Figs. 1 to 6, each of the first and second joining sections (30, 50) gradually and continuously decreases in cross sectional area toward the connecting beam section (40).

Claim 19 further recites the feature of "a lowest fatigue strength portion which is the lowest in fatigue strength [that] exists in at least one of the big and small ends," along with the feature of "a variable fatigue strength portion which varies in fatigue strength that exists in each of the first and second joining sections and in the connecting beam section." Further, according to claim 19, (a) a product of (i) the cross sectional area and (ii) the fatigue strength at a cross section of ***each of the joining and connecting beam section*** is equal to or greater than (b) a product of (iii) the cross sectional area and (iv) the fatigue strength ***in the smallest cross sectional area portion in the connecting beam section***.

As with claim 1, claim 19 provides a connecting rod that is both easily machined in the locations that need machining, and strong in the locations that need strength.

GROUNDS OF REJECTION TO BE REVIEWED ON APPEAL

In the Final Office Action dated September 22, 2005, claims 1, 2, 4, 19 and 21-25 stand variously rejected under 35 U.S.C. §112, first paragraph, 35 U.S.C. §112, second paragraph, and 35 U.S.C. §102(b). As the Advisory Action of February, 2006, provides no relief with respect to any rejection of any claim, it is presumed that the rejections of these claims under each statute section/subsection still stand. Claim 3 is objected to as being dependent from a rejected claim (but would be allowable if placed in independent form).

A brief statement of each ground of rejection follows.

I. Rejections Under 35 U.S.C. §112, First Paragraph

In the Final Office Action, claims 19 and 21-25 were rejected under 35 U.S.C. §112, first paragraph, as failing to comply with the written description requirement.

II. Rejections Under 35 U.S.C. §112, Second Paragraph

In the Final Office Action, claims 19 and 21-25 were rejected under 35 U.S.C. §112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which Appellant regards as the invention.

III. Rejections Under 35 U.S.C. § 102

In the Office Action of September, 2005, Claims 1, 2 and 4 stand rejected under 35 U.S.C. §102(b) as being anticipated by Japanese Utility Model JP 10-306317 ("JP '317"). Claim 1 is further rejected under this same statute in view of U.S. Patent No. 5,048,368 to Mrdjenovich ("Mrdjenovich") or in view of U.S. Patent No. 5,737,976 to Haman ("Haman").

ARGUMENT

Each ground of rejection is traversed for the following reasons.

I. Rejections of Claims 19 and 21-25 Under 35 U.S.C. §112, First Paragraph

In the Final Office Action, claims 19 and 21-25 were rejected under 35 U.S.C. §112, first paragraph, as failing to comply with the written description requirement. Claim 19 is specifically rejected on the grounds that it "claims(s) subject matter which was not described in the specification in such a way as to reasonably convey to one skilled in the relevant art that the inventor at the time the application was filed, had possession of the claimed invention." In support of this rejection, the Office Action alleges that the ***drawings*** do not show features such as "(a) the lowest fatigue strength portion in at least one of the big and small ends 20 and 60," and "(b) the "variable fatigue strength portion in each of the first and second joining sections 30 and 50 and the connecting beam section 40." The Office Action further alleges that "the ***drawings*** do not show any variable fatigue strength portion Q." (September Office Action, paragraph spanning pages 4-5, emphasis added.)

The Office Action further alleges, under the auspices of claiming subject matter which was not described in the specification in such a way as to reasonably convey possession, that it "***is unclear as to how Appellant makes***: (a) the lowest fatigue strength portion in at least one of the big and small ends 20 and 60"; and (b) the "claimed variable fatigue strength portion in the sections 30, 40 and 50." (September Office Action, page 5, first full paragraph, emphasis added.)

In view of the fact that the September 2005 Final Office Action only contains comments directed to independent claim 19 (from which claims 21-25 depend), Appellants hereby argue against the rejection of claims 19 and 21-25 under 35 U.S.C. §112, first paragraph, for failure to comply with the written description requirement as a group, *i.e.*, based only on the wording of independent claim 19.

A. Preliminary Matter: The language of claim 19 is supported by the ***original application as filed***, because claim 19 claim is almost a verbatim copy of both

claim 19 as originally filed and a paragraph in the specification, the only difference being that claim 19 was amended to address possible antecedent basis issues.

Appellants traverse the allegation of failure to comply with the written description requirement, ***relying on (i) the fact that an originally filed claim provides its own support vis-à-vis the written description requirement, and (ii) the fact that language of the specification may be relied on to support a claim with respect to the written description requirement***[1]. In this regard, Appellants provide below a reproduction of claim 19 showing how it differs only slightly from originally filed claim 19, followed by a claim chart comparing claim 19 as pending to the language of the paragraph spanning pages 3-4 (page 3, line 15 to page 4, line 12) of the specification as originally filed.

As may be seen, the only difference between claim 19 as pending, and claim 19 as originally filed and the specification as originally filed is that certain ***portions*** of the connecting rod were provided with a *name*, and a singular/plural antecedent basis issue (which had resulted in a previous indefiniteness rejection) was alleviated. That is, Appellants have only amended claim 19 to alleviate present and future possible antecedent basis issues.

Specifically, instead of reciting "a *portion* which is the smallest in cross sectional area," the claim was amended to recite "a **<u>smallest cross sectional area</u>** *portion* which is the smallest in cross sectional area." That is, "a *portion* which is the smallest in cross sectional area" was simply given a *name*: "a smallest cross sectional area *portion*." The same is the case with respect to "a lowest fatigue strength *portion*," and "a variable fatigue strength *portion*." Finally, the term "sections" was amended to "section" to overcome the antecedent basis rejection present in the prior Office Action (the Office Action of March, 2005).

19. (As compared to originally filed claim 19) A high-strength connecting rod comprising:

a connecting beam section serving as a main body of the connecting rod, the connecting beam section having a **<u>smallest cross</u>**

[1] Applicants note that the PTO does not allege that the ***<u>amendments</u>*** to claim 19 run afoul of the written description requirement; the Office Action's only basis its rejection for lack of written description support on the allegation of deficiencies in the drawings and the allegation that it is unclear as to how to make the connecting rod of claim 19 (both of which are unfounded), as will be detailed below. Regardless, Applicants hereby undertake an analysis of the amendments to claim 19 to remove all possible doubt as to whether claim 19 has support in the originally filed application.

sectional area portion which is the smallest in cross sectional area throughout the connecting rod;

a big end located at a first end side of the connecting beam section;

a small end located at a second end side of the connecting beam section, the second end side being axially opposite to the first end side;

a first joining section located between the connecting beam section and the big end to connect the connecting beam section and the big end; and

a second joining section located between the connecting beam section and the small end to connect the connecting beam section and the small end;

wherein each of the first and second joining sections gradually and continuously decreases in cross sectional area toward the connecting beam section;

wherein a **lowest fatigue strength** portion which is the lowest in fatigue strength exists in at least one of the big and small ends, and a **variable fatigue strength** portion which varies in fatigue strength exists in each of the first and second joining sections and in the connecting beam ~~sections~~ **section**;

wherein a product of the cross sectional area and the fatigue strength at a cross section of each of the joining and connecting beam ~~sections~~ **section** is equal to or greater than a product of the cross sectional area and the fatigue strength in the smallest cross sectional area portion in the connecting beam section.

Claim 19 as Pending:	**Specification As Originally Filed, Page 3, line 15 to page 4, line 12:**
A high-strength connecting rod comprising:	A third aspect of the present invention resides in a high-strength connecting rod comprising
a connecting beam section serving as a main body of the connecting rod, the connecting beam	a connecting beam section serving as a main body of the connecting rod, the

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section having a smallest cross sectional area portion which is the smallest in cross sectional area throughout the connecting rod;	connecting beam section having a portion which is the smallest in cross sectional area throughout the connecting rod.
a big end located at a first end side of the connecting beam section;	A big end is located at a first end side of the connecting beam section.
a small end located at a second end side of the connecting beam section, the second end side being axially opposite to the first end side;	A small end is located at a second end side of the connecting beam section, the second end side being axially opposite to the first end side.
a first joining section located between the connecting beam section and the big end to connect the connecting beam section and the big end; and	A first joining section is located between the connecting beam section and the big end to connect the connecting beam section and the big end.
a second joining section located between the connecting beam section and the small end to connect the connecting beam section and the small end;	A second joining section is located between the connecting beam section and the small end to connect the connecting beam section and the small end.
wherein each of the first and second joining sections gradually and continuously decreases in cross sectional area toward the connecting beam section;	In this connecting rod, each of the first and second joining sections gradually and continuously decreases in cross sectional area toward the connecting beam section.
wherein a lowest fatigue strength portion which is the lowest in fatigue strength exists in at least one of the big and small ends, and a variable fatigue strength portion which varies in fatigue strength exists in each of the first and second	Additionally, a portion which is the lowest in fatigue strength exists in at least one of the big and small ends, and a portion which varies in fatigue strength exists in each of the first and second joining

joining sections and in the connecting beam section;	sections and in the connecting beam sections.
wherein a product of the cross sectional area and the fatigue strength at a cross section of each of the joining and connecting beam section is equal to or greater than a product of the cross sectional area and the fatigue strength in the smallest cross sectional area portion in the connecting beam section.	Further, a product of the cross sectional area and the fatigue strength at a cross section of each of the joining and connecting beam sections is equal to or greater than a product of the cross sectional area and the fatigue strength in the smallest cross sectional area portion in the connecting beam section.

As may be clearly seen from the above, there was irrefutable written description support for current claim 19 at the time that the application was filed. Apart from a few grammatical differences, originally filed claim 19 and the language of the paragraph spanning pages 3 to 4 of the specification is an exact duplicate of the language of the claim. Clearly, then, the skilled artisan would have recognized that Appellants had possession of the claimed subject matter.

Further, MPEP §2106(V)(B), entitled "Determining Whether the Claimed Invention Complies with 35 U.S.C. §112, First Paragraph Requirements," subsection 1, states, immediately after discussing the "reasonable conveyance" requirement (used as a basis to reject claim 19 and its dependencies) that the "claimed invention subject matter *need not be described literally, i.e., using the same terms*, in order for the disclosure to satisfy the description requirement." (Emphasis added) Appellants respectfully submit that the claims of the present invention find sufficient written description in the as-filed specification.

B. <u>First Allegation in the Office Action Regarding Written Description</u>: The Office Action alleges, to support the rejection of claim 19 as failing to comply with the written description requirement, that "the ***drawings*** do not show the claimed features such as "(a) the lowest fatigue strength portion in at least one of the big and small ends 20 and 60." (September Office Action, paragraph spanning pages 4-5, emphasis added.)

Notwithstanding the fact that claim 19 has almost verbatim support in the originally filed application, as detailed above, Appellants further submit that failure to show a claimed feature in the drawings of an application (assuming *arguendo* that this is the case), in view of an adequate originally filed claim and/or an adequate specification text, does not and cannot result in a written description deficiency, as the specification and/or claims, without the drawings, may provide written description for a claim. (For that matter, an adequate text without any drawings may also provide enablement as well.)

Further, "the lowest fatigue strength portion" is, at least in part, governed by material property, and thus there is no way to schematically show this feature. By way of analogy, a piece of 304 stainless steel heat treated to 150 KSI would look the same even if it was instead heat treated to 170 KSI (the former being of *lower* fatigue strength), at least in regards to the ink drawn schematics utilized in a patent application. It is submitted that the ordinary artisan would not need a schematic representation of "a lowest fatigue strength portion" to recognize that Appellants were in possession of the invention as claimed in claim 19 – the specification and originally filed claim 19 proving such evidence of possession.

Appellants respectfully submit that the MPEP supports the above positions taken by Appellants in traversing the rejection of claim 19 under 35 U.S.C. §112, first paragraph. For example, Appellants point to MPEP §2163.04(i) entitled "***Burden on the Examiner*** with Regard to the Written Description Requirement," (emphasis added) which states that the

> inquiry into whether the description requirement is met must be determined on a case-by-case basis and is a question of fact. *In re Wertheim*, 541 F.2d 257, 262, 191 USPQ 90, 96 (CCPA 1976). A description as filed is presumed to be adequate, unless or until sufficient evidence or reasoning to the contrary has been presented by the examiner to rebut the presumption. See, e.g., *In re Marzocchi*, 439 F.2d 220, 224, 169 USPQ 367, 370 (CCPA 1971). The examiner, therefore, must have a reasonable basis to challenge the adequacy of the written description. The examiner has the initial burden of presenting by a preponderance of evidence why a person skilled in the art would not recognize in an Appellant's disclosure a description of the invention defined by the claims. *Wertheim*, 541 F.2d at 263, 191 USPQ at 97.

It is respectfully submitted that no evidence has yet been proffered by the PTO to support the rejection of claim 19 under 35 U.S.C. §112, first paragraph. Appellants provide further excerpts from this MPEP section in Exhibit Appendix I in support of their position, and respectfully submit that the requirements of the MPEP vis-à-vis establishing a *prima facie* case of a lack of written description have not been established.

C. <u>Second Allegation in the Office Action Regarding Written Description</u>: The Office Action alleges that "the ***drawings*** do not show the claimed features such as, . . . (b) the "variable fatigue strength portion in each of the first and second joining sections 30 and 50 and the connecting beam section 40." (Final Office Action, paragraph spanning pages 4-5, emphasis added.)

In response, Appellants refer to the above discussions in section "B" regarding this allegation, as this allegation is not valid with respect to the written description requirement for the same reasons detailed with respect to the allegation that the drawings do not show the lowest fatigue strength portion.

D. <u>Third Allegation in the Office Action Regarding Written Description</u>: The Office Action alleges that it "is unclear as to how Appellant makes: (a) the claimed lowest fatigue strength portion in at least one of the big and small ends 20 and 60; and (b) the claimed variable fatigue strength portion in the sections 30, 40 and 50." (September Office Action, page 5, first full paragraph.)

First, assuming *arguendo* that the factual premise in the Final Office Action were true, this has no bearing on whether a claim fails the written description requirement in view of an adequate originally filed specification. Second, Appellants respectfully submit that the ordinary artisan would have understood how to make the claimed invention based on the specification as originally filed. Again, the presence or absence of drawings, in and of itself, does not govern the question of whether the skilled artisan would have understood how to make an invention . (It further has nothing to do with the written description requirement of a claim containing language that is almost exactly verbatim from an originally filed specification.)

E. <u>Allegation Made During the Interview of January 18, 2006, Regarding Written Description</u>: During the interview of January 18, 2006, the PTO alleged that there is no support for claim 19 because the specification uses the term "<u>or</u>" and claim 19 uses the phrase "<u>at least one of</u>" with respect to the big and small ends.[2] In response, Appellants traverse this assertion, ***relying on the fact that an originally filed claim provides its own support vis-à-vis the written description requirement***. (Interview Summary of January 18, 2006). In this regard, claim 19, as originally filed, uses the language "*at least one of*," [3]and thus there is written description support for claim 19 in the originally filed application.

Further, as seen above, the paragraph spanning pages 3-4 also utilizes the language "at least one of" with respect to the big and small ends. Thus, the specification provides support for this claim as well.

However, in order to advance prosecution, and without prejudice or disclaimer, Appellants proffered an amendment to the specification, as seen above, to recite on page 24 the exact language at issue of claim 19. No new matter has been added in view of originally filed claim 19 and specification at pages 3-4. This amendment was refused entry on the grounds that the preamble "In another embodiment" "raises new issues that would require further consideration." Although Appellants disagree, and submit that no new issues are raised by this amendment, they likewise do not believe that the above proffered amendment to page 24 is necessary, as the specification and originally filed claim 19 support the claim language "in at least one of" the big and small ends.

In sum, claims 19 and 21-25 are supported by the specification as originally filed. These claims do not fail the written description requirement, and the absence of claimed

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[2] Specifically, it was alleged that there is no support for claim 19 because the specification, at page 24, lines 11-14, states that the "connecting rod has a portion of the smallest cross sectional area in its connecting beam section, a portion of the lowest fatigue strength at its big ***<u>or</u>*** small end," as compared to the recitation of "a lowest fatigue strength portion which is the lowest in fatigue strength exists **<u>in at least one of</u>** the big and small ends, and a variable fatigue strength portion which varies in fatigue strength exists in each of the first and second joining sections and in the connecting beam section."

[3] Claim 19, as originally filed, recites "wherein a portion which is the lowest in fatigue strength exists in ***<u>at least one of</u>*** the big and small ends, and a portion which varies in fatigue strength exists in each of the first and second joining sections and in the connecting beam sections." (Emphasis added.)

subject matter in the drawings is not dispositive of this issue. Reversal of the rejections under 35 U.S.C. §112, first paragraph, is respectfully requested.

II. Rejections Under 35 U.S.C. §112, Second Paragraph

In the Final Office Action, claims 19 and 21-25 were rejected under 35 U.S.C. §112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which Appellant regards as the invention. The basis of the rejection appears to be the alleged lack of a depiction of various claim features in the ***drawings***.

A. <u>First Allegation in the Office Action Regarding Indefiniteness</u>: The September 2005 Office Action asserted that it "is unclear which portions of the connecting rod are the lowest fatigue strength portion and the variable fatigue strength portion claimed in claim 19. Appellant is respectfully urged to identify each claimed element with reference to the ***drawings***." (Page 5, third full paragraph, emphasis added.)

Appellants respectfully submit that, assuming *arguendo* there is in fact a lack of such depiction, this does not make the claims indefinite. The claims clearly define the invention. Claim 19 reads:

> wherein a ***lowest fatigue strength portion which is the lowest in fatigue strength*** exists in at least one of the big and small ends, and ***a variable fatigue strength portion which varies in fatigue strength exists*** in each of the first and second joining sections and in the connecting beam section.

(Emphasis added.) Appellants submit that the claimed portions are self-defining, and thus it is clear which portions of the connecting rod are which. Although the claims may be broad, this fact alone does not make them indefinite. (MPEP §2173.04)

Appellants respectfully remind the PTO that claims are to be evaluated with the ordinary skill test: "Acceptability of the claim language depends on whether one of ordinary skill in the art would understand what is claimed, in light of the specification." (MPEP §2173.05(b).) Appellants respectfully submit that one of ordinary skill would readily

understand claims 19 and 21-25, and no evidence has been proffered to the contrary. Reconsideration is requested.

B. **<u>Second Allegation in the Office Action Regarding Indefiniteness</u>:** The September 2005 Office Action asserts that the recitations following the second "wherein" clause in claim 19 (see above chart) are not "understood since the ***drawings***, such as, Figs. 1, 2, 11, 20, and 21 ***do not show the instant claimed features***." (Page 5, fourth full paragraph, emphasis added.)

In response, Appellants again submit that the drawings are not definitive of whether a claim is indefinite, and submit that the recitations of claim 19 at issue in this allegation are not indefinite for the pertinent reasons just detailed above in section "A."

In sum, claim 19 and 21-25 are not indefinite. Reversal of this rejection is respectfully requested.

III. Rejections Under 35 U.S.C. § 102

There are only two issues that need be resolved to determine whether the claims are anticipated in view of the prior art, both of which are interrelated: **(1)** is the Office Action correct, both procedurally and factually, to ***disregard*** a recitation in claim 1 on the grounds that the recitation only recites *inherent* features of previous claim elements (Appellants say no, it is not an inherent feature), and **(2)** is the Office Action correct, both procedurally and factually, in its assertion that the disregarded recitation is ***inherently*** present in the cited prior art references (to which Appellants also say no)?

The specifics of the rejections will now be discussed.

In the Office Action of September, 2005, Claims 1, 2 and 4 stand rejected under 35 U.S.C. §102(b) as being anticipated by Japanese Utility Model JP 10-306317 ("JP '317").

Claim 1 (but no other) is further rejected under this same statute in view of U.S. Patent No. 5,048,368 to Mrdjenovich ("Mrdjenovich") or in view of U.S. Patent No. 5,737,976 to Haman ("Haman").

MPEP § 2131, entitled "Anticipation – Application of 35 U.S.C. 102(a), (b), and (e)," states that a "claim is anticipated only if each and every element as set forth in the claim is found, either expressly or inherently described, in a single prior art reference." Section 103 amplifies the meaning of this anticipation standard by pointing out that anticipation requires that the claimed subject matter must be "*identically* disclosed or described" by the prior art reference. (Emphasis added.) It is respectfully submitted that the cited references do not describe (expressly or inherently) each and every element of independent claim 1, and thus also does not describe the subject matter of the claims that depend therefrom.

A. <u>Claim Element that is Missing from all the References is not an Inherent Feature of the Other Claim Elements</u>: Claim 1 recites that "each of the first and second ***joining sections*** gradually and continuously decreases in cross sectional area toward the connecting beam section and ***has a strength distribution in which a strength increases with a decrease in the cross sectional area.***" (Emphasis added.) That is, there are two portions of the connecting rod where, as there is *less and less* material present, the strength of the connecting rod *increases*, in contrast to how strength usually *decreases* with *less and less* material present. In an exemplary embodiment according to claim 1, this strength distribution is achieved by "controlling hardening by heat treatment (hardening), so that a distribution may be produced in the hardening temperature and/or tempering time during the quenching of the joining sections." (Specification, page 12, lines 21-26.) The strength distribution is thus obtained as a result of different material properties at various locations of the connecting rod. The claim does link the strength distribution to the geometry of the joining sections, because this is where the claimed phenomenon takes place, to differentiate the invention from the prior art, but it is a change in material properties along the connecting rod that gives rise to the strength distribution.

The Final Office Action is not entirely clear as to how it treats this recitation. While first asserting that the cited references teach each element of claim 1, the Office Action goes on to assert that the above-quoted recitation is an ***inherent result*** of the other features of claim 1 (Final Office Action, paragraph spanning pages 6-7, and pages 10 and 11), thus raising ambiguity as to whether the Office Action gives patentable weight to this recitation.

Appellants therefore first address the fact that the patentably distinct language following the "wherein" clause is a feature of the invention that must be given patentable weight, as it is impossible to evaluate the prior art without first determining the scope of the claims. (The facts that relate to why the strength distribution recitation is not an inherent feature of the other elements of claim 1 also relate to why the claimed distribution is not inherently present in the prior art, and thus the two questions are intertwined.)

In apparent support of its action to disregard the above-quoted language, the Office Action cites *Texas Instruments v. ITC*,[4] and *Griffin v. Bertina*[5] as standing for the position that "the 'wherein' clause or 'whereby' clause that merely expresses an inherent result, adds nothing to claim's patentability." (Final Office Action, page 6, paragraph spanning pages 6 and 7.) *Texas Instruments* dealt with the clause "***whereby***," not "***wherein***." *Griffin* did deal with the term "wherein" (albeit in the context of establishing a reduction to practice date in an interference), but held that the wherein clause ***could <u>not</u>*** be disregarded. Specifically, the court in *Griffin* stated that they were

> not persuaded by Griffin's arguments that the "wherein" clauses merely state the inherent result of performing the manipulative steps. A party seeking to show that it need not establish reduction to practice of every feature recited in the count based on the alleged inherency of some of those features must show that the "inherent" properties add nothing to the count beyond the other recited limitations and are not material to the patentability of the invention.

Griffin V. Bertina, 285 F.3d 1029, 62 USPQ2d 1431, 1434 (Fed. Cir. 2002).

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[4] *Texas Instruments v. International Trade Commission,* 988 F.2d 1165, 26 USPQ2d 1018 (Fed. Cir. 1993).

[5] *Griffin V. Bertina,* 285 F.3d 1029, 62 USPQ2d 1431 (Fed. Cir. 2002).

Moreover, even if these case were to be abstracted to cover the present situation, the result of *Texas Instruments* would not apply, and the result of Griffin would apply (the strength distribution recitation would be considered a recitation), because the above-quoted language does more than merely express an inherent result. That is, the case law cited in the Office Action only supports a decision that each claim recitation in claim 1 must be given patentable weight.

The key issue in *Texas Instruments* and *Griffin* was the determination of whether a claimed feature was an ***inherent or necessary*** result of the other claim recitations. "Inherent" means that ***a feature is necessarily present***. (See MPEP § 2112 – discussed in greater detail below with respect to the prior art.) That is, the feature is always present.

The above-quoted recitation regarding the strength distribution is not ***necessarily present*** in the prior recited elements of claim 1. This is ***evinced by the fact that in prior art connecting rods, strength <u>decreases</u> with a decrease in cross sectional area***, and thus an increase in strength with decreasing cross section is not ***always*** present. That is, the strength distribution clause of claim 1 does more than merely express an inherent result. There is simply nothing in the recitations preceding this language that ***require*** (or even suggest, for that matter) that "the first and second joining sections gradually and continuously decrease in cross sectional area toward the connecting beam section" have "a strength distribution in which a strength increases with a decrease in the cross sectional area," as would be necessary for a result to be ***inherent***.

The PTO neither cites evidence nor sets forth any explanation to support its position that the above quoted language, following the "wherein" clause of claim 1, is an inherent result of the prior recitations. In fact, aside from misapplying two cases (*Texas Instruments* and *Griffin*), one of which (*Griffin*) supports giving patentable weight to the recitations at issue, the only other arguments apparently made in support of this position are circular, asserting simply that because claim 1 recites certain features, the other feature is inherent.

(This is discussed in greater detail at the end of this section.) Appellants submit that, for the PTO to maintain its assertion of inherency, the PTO must identify which element of claim 1 results in the inherency of the above-quoted language **and explain why that element results in a strength distribution that increases with decreasing cross sectional area, instead of decreasing with decreasing cross sectional area**

Appellants respectfully submit that the claimed elements, individually or combined in any combination, do not inherently result in ***a strength distribution in which a strength increases with a decrease in the cross sectional area***, and the PTO has not proffered evidence to the contrary.

Indeed, Appellants submit just the opposite: that the elements of claim 1 prior to the above-quoted language, *without more*, do not result in joining sections having a strength distribution in which a strength increases with a decrease in the cross sectional area. Appellants "more" is obtained as detailed in the specification (controlled martensitic transformation, *etc.*) and differentiates the invention of claim 1 from the prior art. The recited strength distribution is not an inherent feature of the prior recited elements, and, in fact, is opposite of what is usually the case (the strength distribution is one that usually decreases with a decrease in the cross sectional area). This is the case not only with the preceding elements of claim 1, but the connecting rods of the prior art as well, as will be detailed below.

The paragraph spanning pages 10-11 of the Final Office Action states that it is known that "the strength of material improves by the hardening, heat-treatment, and cold forging process, *etc.*" citing the text "*Mechanical Design and Systems Handbook.*" Appellants do not deny this is the case with respect to most steels. The Office Action goes on to assert that "Appellant uses the methods such as hardening, heat-treatment, and cold forging process." Appellants do not deny the use of heat-treatment in obtaining embodiments of their connecting rod, ***although the use of heat-treatment is not recited in claim 1***. The Office Action then comes to the conclusion that "[t]herefore, the strength distribution of Appellant's connecting rod ***must*** be improved particularly in the areas where the cross sectional [sic] is decreased to prolong life of the connecting rod as taught by standard text books." (Emphasis

added.) That is, because Appellants utilize a process that is ***not recited*** in claim 1, the results of that process must necessarily be present in / flow from claim recitations that have nothing to do with the unclaimed process (which of the above 6 claim elements is related to heat-treatment?). Because heat-treatment is not claimed in claim 1, this argument further underscores the fact that the recited strength distribution is not inherently present in the preceding claim elements.

Also, there is nothing about the preceding facts (heat-treatment is known to improve the strength of most steels, and Appellants use heat-treatment to prepare embodiments of their connecting rod) that results in a scenario where "the strength distribution of Appellant's connecting rod ***must*** be improved particularly in the areas where the" cross sectional area is decreasing. This evinces, at most, only the capability of "improving" strength. Further, even if the alleged "must" result is the case, it still does not result in a strength distribution that increases with decreasing cross sectional area. Instead, it results in, *arguendo,* a strength distribution that is "improved" in the areas where cross sectional area is decreasing. "Improvement" is not the same as the strength distribution as claimed. Indeed, these arguments presented in the Office Action further underscore the fact that the strength distribution recitation is decidedly not inherent in the preceding claim recitations. It is respectfully submitted that it is wrong that the Office Action does not view the claimed strength distribution as giving patentable weight to the invention, as the claimed strength distribution is not an ***inherent*** feature of any of the preceding claims, and, in fact, differentiates the present invention from the prior art.

In sum, the recitation of ***a strength distribution in which a strength increases with a decrease in the cross sectional area*** is not an inherent feature of the previous claimed elements in claim 1 (nor is it an inherent feature of the prior art, as will be discussed below), and thus this recitation must be given patentable weight.

B. **First Allegation of Anticipation:** The September Office Action incorrectly alleges that claims 1, 2 and 4 are anticipated under 35 U.S.C. §102(b) by JP '317.

1. All Claims

JP '317 teaches a connecting rod. Assuming *arguendo* that JP '317 meets each and every recitation of claim 1 prior to the strength distribution recitation, JP '317 does not teach, either expressly or inherently, first and second joining sections that gradually and continuously decrease in cross sectional area as recited ***and have a strength distribution in which a strength <u>increases</u> with a <u>decrease</u> in the cross sectional area.***

The Office Action asserts on page 6 that JP '317 teaches each element of claim 1, reciting all of claim 1, word for word. After each recited element, the Office Action identifies where the element may be found in the art, ***with the exception of the recitation regarding the <u>strength distribution</u>***. This is because JP '317 does not teach this distribution.

There is no teaching, either expressly or inherently, in JP '317, that the alleged ***joining sections*** have a strength distribution in which a strength increases with a decrease in the cross sectional area, where ***the joining sections are respectively located between*** the connecting beam section and the big end to connect the connecting beam section and the big end, and located between the connecting beam section and the small end to connect the connecting beam section and the small end, as is recited in claim 1. No evidence is proffered by the PTO to the contrary.

Various cross sections are depicted in Figure 12 of JP '317, and there are numerical values associated with various positions within the cross sections. It is unclear what these numerical values mean, but assuming *arguendo* that these numerical values are related to "strength," JP '317 still does not anticipate claim 1. This is at least because no cross section is present in any ***joining section*** of JP '317. Instead, cross sections "A" and "C" are taken through the big end and the little end, and cross section "B" is taken through the connecting portion. These are not through any joining section, and thus, to the extent that JP '317 teaches features of the material properties at these locations (assumed *arguendo* to be the case), JP '317 still does not teach, either expressly or inherently, features regarding the strength distribution in any joining sections.

It is unclear whether the Office Action relies on an inherency argument to remedy the above identified deficiencies of JP '317 or whether the inherency argument is used (incorrectly) to simply eviscerate the strength distribution recitation from the claim, as detailed in section "A" above. To the extent that the Office Action is asserting that the prior art inherently has the claimed strength distribution, Appellants traverse such assertion, pointing to MPEP §2112, which states that while "a rejection under 35 U.S.C. §102/103 can be made when the prior art product seems to be identical except that the prior art is silent to an inherent characteristic," the "[E]xaminer ***must*** provide ***rationale or evidence*** tending to show inherency." (MPEP § 2112, subsections 3 and 4, emphasis added.) It is respectfully submitted that no evidence tending to show inherency has been provided in the present Office Action. Further, in considering how the inherency concept is being used in the Office Action, it is respectfully submitted that § 2112 inherency is not being properly implemented. In arriving at this conclusion, Appellants rely on the following excerpt from MPEP § 2112:

> The fact that a certain result or characteristic may occur or be present in the prior art is not sufficient to establish the inherency of that result or characteristic. *In re Rijkaert*, 9 F.3d 1531, 1534, 28 USPQ2d 1955, 1957 (Fed. Cir. 1993) (reversed rejection because inherency was based on what would result due to optimization of conditions, not what was necessarily present in the prior art); *In re Oelrich*, 666 F.2d 578, 581-82, 212 USPQ 323, 326 (CCPA 1981). "To establish inherency, the extrinsic evidence 'must make clear that ***the missing descriptive matter is necessarily present*** in the thing described in the reference, and that it would be so recognized by persons of ordinary skill. Inherency, however, may not be established by probabilities or possibilities. The mere fact that a certain thing may result from a given set of circumstances is not sufficient.'" *In re Robertson*, 169 F.3d 743, 745, 49 USPQ2d 1949, 1950-51 (Fed. Cir. 1999) (citations omitted) (The claims were drawn to a disposable diaper having three fastening elements. The reference disclosed two fastening elements that could perform the same function as the three fastening elements in the claims. The court construed the claims to require three separate elements and held that the reference did not disclose a separate third fastening element, either expressly or inherently.)

(Emphasis added.) Inherency means that *the missing descriptive matter is necessarily present* in the reference. The courts have allowed the PTO to rely on inherency arguments to free the

PTO from the necessity of finding references which explicitly state that inherent elements are present. This is because certain characteristics are inherent, the references will most probably not mention these elements, and, as such, will be difficult to find. For example, it is not necessary to find a reference that explicitly states that plutonium 239 is radioactive, as plutonium 239 is always radioactive. That is, radioactivity is an inherent feature of plutonium 239. However, inherency is not a panacea that enables the PTO to use references which are *deficient* in teaching certain elements of a claim. Recognizing the power of the inherency argument, the courts have tempered its use, as is seen in § 2112, where the PTO has stipulated that examiners must follow certain procedures before invoking inherency: the "examiner must provide rationale or evidence tending to show inherency." In the present case, no such rationale or evidence has been provided in the Office Action. Just because it may be ***desirable or useful*** to have a connecting rod having a strength distribution as claimed does not mean that such properties are ***always*** present. Just the opposite is true: as pointed out above, connecting rods typically have strength distributions that decrease with decreasing cross sectional area. The subject matter claimed in claim 1 is not ***necessarily present*** in the references. It is entirely probable that the references will be practiced without a strength distribution that changes as claimed. Just as was the case of the third fastener in the example provided in the MPEP quoted above, the subject matter of Appellants' claims is not expressly or inherently disclosed in any of the cited references.

With the above in mind, the Office Action asserts on the second full paragraph on page 11 of the Final Office Action that

> the connecting rod of JP '317, Mrdjenovich, and Haman have joining sections that are gradually and continuously decreased in cross sectional area towards a connecting beam. Thus, the connecting rods of JP '317, Mrdjenovich, and Haman are expected to behave in the same manner as Appellant's connecting rod because they all have the same sectional profiles.

That is, the Office Action asserts that because the connecting rods of the prior art look like they fall within the scope of ***some*** of the recitations of claim 1, the ***other*** recitations are met by the prior art. This is not the standard for rejecting a claim as anticipated, and to the extent

that the Office Action is asserting an inherent result or characteristic, insufficient evidence / rationale has been proffered.

Still further, as demonstrated above in section "A," the strength distribution is not an inherent feature of any of the preceding elements of claim 1, and, therefore, to the extent that corresponding elements may be found in a prior art reference, it necessarily follows that, without more, those corresponding elements likewise do not have as an inherent feature the strength distribution as claimed.

To reiterate, as detailed in the specification (and above), Appellants obtain their strength distribution by the way portions of the connecting rod are treated – some portions are treated differently from other portions of the connecting rod during the manufacturing process to obtain different material properties (*see, for example,* Fig. 9 in view of Fig. 1). The claimed strength distribution is thus obtained as a result of different material properties at various locations of the connecting rod. By linking the strength distribution to the geometry of the joining sections, Appellants differentiate the apparatus invention from the prior art, but it is a change in material properties along the different sections of the connecting rod that gives rise to the claimed strength distribution. Accordingly, two connecting rods that may have the exact same dimensions may also have different structural characteristics due to the strength of the material. Thus, even though schematics of the prior art may look like they fall within the scope of some of the claim elements of claim 1, the prior art does not inherently teach the remaining elements of claim 1.

In sum, claim 1 is not anticipated because the prior art does not teach, either expressly or inherently, a connecting rod having first and second joining sections that gradually and continuously decrease in cross sectional area toward a connecting beam section and having a strength distribution in which a strength increases with a decrease in the cross sectional area.

2. Claim 2:

Claim 2 recites a connecting rod as claimed in Claim 1, wherein the strength distribution is based on a proportion (%) of martensite. Claim 2 is allowable at least due to its dependency from claim 1, but also because JP '317 does not teach, either expressly or inherently, this feature.

In rejecting claim 2, the Office Action repeats the recitations of claim 2, and asserts that the English abstract of JP '317 teaches these recitations. (See first full paragraph of page 7 of the September Office Action.) While it is true that JP '317 does refer to quenching to promote martensitic transformation, there is no teaching in JP '317 that the specific strength distribution is based on a proportion (%) of martensite. Thus, the Office Action appears to be making another inherency argument.

Indeed, the Office Action acknowledges that "JP '317 does not ***explicitly*** so describe[e]"the recitations of claim 2. (Final Office Action, end of paragraph spanning pages 11-12, emphasis added). Thus, for JP '317 to anticipate claim 2, it must ***inherently*** teach each element of the claim, as MPEP § 2131 states that a "claim is anticipated only if each and every element as set forth in the claim is found, either ***expressly*** or ***inherently*** described, in a single prior art reference." Therefore because, as the Office Action recognizes, JP '317 does not explicitly describe claim 2, the only way for JP '317 to anticipate claim 2 is for the missing recitations of claim 2 to be inherent in JP '317, which it is not.

As discussed above with respect to claim 1, inherency means that the missing subject matter is necessarily present – it is always there (MPEP §2112). It is not always the case that a strength distribution is controlled by the percentage of martensite in a structure. This is because there are other structures may be present in JP '317 that would influence the strength. For example, the presence of ***bainite*** would influence the strength distribution, and thus it does not necessarily follow that simply because a structure contains martensite, that structure has a strength distribution that changes on a proportion of martensite, as bainite that is present also influences the strength. In support of this proposition, Appellants proffered an article entitled *Review of the Performance of High Strength Steels Used Offshore* [6] in the Response

[6] *Review of the Performance of High Strength Steels Used Offshore*, prepared by Cranfield University, 2003 (e.g., pages 6, 35, 71, 107 and 110), ***evincing that bainite influences strength***.

of January, 2006, as evidence rebutting the position taken in the Office Action regarding an inherent relation between the presence of martensite in a steel and a strength distribution based on a proportion of martensite.

In the paragraph spanning pages 11-12 of the Final Office Action, the Office Action asserts that it is known that the presence and amount of Martensite present in a steel component may influence strength. Appellants agree. However, JP '317 does not teach a strength distribution ***which varies as claimed*** is based on a proportion of martensite. JP '317 only teaches that a martensitic transformation takes place. Thus, JP '317 does not teach a variation in strength based on a percentage of martensite.

The Office Action generally points to an entire chapter of a text book, *Mechanical Design and Systems Handbook*, (Exhibit Appendix II), ***without specifying a specific page or range of pages of the 33 pages cited***, alleging that the handbook "clearly teach [sic] that the strength distribution is based on a proportion (%) of martensite." (September Office Action, last sentence of paragraph spanning pages 11-12.) This is not so. All that the handbook teaches is that martensite influences the strength of steel. The handbook says nothing about a strength distribution within a piece of steel being based on a proportion of martensite, and nothing about a distribution that ***varies*** as claimed based on a proportion of martensite. Appellants respectfully submit that the recitations of claim 2 are not sufficiently being examined.

Because JP '317 does not explicitly teach each element of claim 2, as is admitted in the Office Action, and because JP '317 does not inherently teach each element of claim 2, claim 2 is not anticipated for a second reason (the first being due to its dependency).

3. Claim 4:

Claim 4 recites a connecting rod as claimed in Claim 2, wherein the strength distribution is formed based on a distribution in at least one of a hardening temperature and a tempering time for each of the first and second joining sections.

In rejecting claim 4, the Final Office Action asserts that the "strength distribution is ***inherently*** formed based on [replication of the claim language of claim 4]," citing the Derwent English language translation of the abstract of JP '317. (September Office Action, page 7, emphasis added.) The Office Action goes on to again generally rely on chapter 17 *Mechanical Design and Systems Handbook*, this time asserting that an entire chapter (without specifying a page or a page range within the chapter) "clearly teach [sic] that the strength distribution is inherently or must be based on [the claim langue of claim 4]." (September Office Action, page 12, first full paragraph.)

Appellants respectfully submit that there is nothing in the Derwent English Abstract of JP '317 that demonstrates that the strength distribution is *inherently* formed based on a distribution in at least one of a hardening temperatures and a tempering time for each of the first and second joining sections. First, there is no reference to temperature or time in the Abstract. Second, for a feature to be inherent, that feature must occur each and every time, pursuant to MPEP §2112. Since there is no evidence that this feature occurs each and every time the teachings of JP '317 are implemented, claim 4 is not inherently anticipated by this reference.

Moreover, there is nothing in the cited *handbook* regarding a strength distribution within a piece of steel, and nothing regarding a strength distribution that varies as claimed. Further, strength may be influenced by factors other than hardening temperature and a tempering time, such as, for example, whether the metal was cold worked, the composition of the metal, *etc*. Thus, assuming *arguendo* that a reference may be found that teaches that a strength distribution may be based on hardening temperature and tempering time, such a reference still does not make it inherent (*i.e.*, it is ***always*** the case) that JP '317 teaches a strength distribution that is "formed based on a distribution in at least one of a hardening temperate and a tempering time,." as there are other ways to influence strength, and JP '317 is silent as to time and temperature.

In summary, claim 4 is not anticipated because JP '317 does not inherently teach each element of this claim, in addition to being allowable due to its dependency from claim 1.

C. **Second Allegation of Anticipation:** The Final Office Action alleges that claim 1 is anticipated under 35 U.S.C. §102(b) by Mrdjenovich. Specifically, the Office Action directs the Appellant to see "cross sections shown in Figs. 7 and 6 that gradually and continuously decrease in cross sectional area towards the connecting beam section 11 as seen in Figs. 2 and 3." (September Office Action, page 7, fourth full paragraph.) The Office Action goes on to assert that the connecting rod of Mrdjenovich is "expected to behave in the same manner as Appellant's connecting rod because [it has] the same sectional profiles." (September Office Action, page 11, second full paragraph.)

As with JP '317, the Office Action never identifies where Mrdjenovich teaches a connecting rod where "each of the first and second ***joining sections*** gradually and continuously decreases in cross sectional area toward the connecting beam section and ***has a strength distribution in which a strength increases with a decrease in the cross sectional area.***" Instead, the Office Action again merely asserts, as it did with JP '317, that because the connecting rods of the prior art look like they fall within the scope of ***some*** of the recitations of claim 1, the ***other*** recitations are met by the prior art. Again, Appellants reiterate that this is not the standard for rejecting a claim as anticipated. Moreover, as this feature is not inherent in the prior recitations of claim 1, there is no reason to believe that this feature is inherently present in any corresponding recitations, as detailed above with respect to JP '317.

Appellants thus traverse the rejection of claim 1 in view of Mrdjenovich, and submit that the same arguments detailed above with respect to the deficiencies of JP '317 are applicable to Mrdjenovich.

D. **Third Allegation of Anticipation:** The September Office Action alleges that claim 1 is anticipated under 35 U.S.C. §102(b) by Haman. Specifically, the Office Action

directs the Appellant to see "cross sections 103 and 105 shown in Fig. 2 that gradually and continuously decrease in cross sectional area towards the connecting beam section 101." (September Office Action, page 7, sixth full paragraph.) The Office Action goes on to assert that the connecting rod of Haman is "expected to behave in the same manner as Appellant's connecting rod because [it has] the same sectional profiles." (September Office Action, page 11, second full paragraph.)

As with JP '317, the Office Action never identifies where Haman teaches a connecting rod where "each of the first and second ***joining sections*** gradually and continuously decreases in cross sectional area toward the connecting beam section and ***has a strength distribution in which a strength increases with a decrease in the cross sectional area.***" Instead, the Office Action again merely asserts, as it did with JP '317, that because the connecting rods of the prior art look like they fall within the scope of ***some*** of the recitations of claim 1, the ***other*** recitations are met by the prior art. Again, Appellants reiterate that this is not the standard for rejecting a claim as anticipated. Again Appellants also point out that as this feature is not inherent in the prior recitations of claim 1, there is no reason to believe that this feature is inherently present in any corresponding recitations, as detailed above with respect to JP '317.

Appellants thus traverse the rejection of claim 1 in view of Haman, and submit that the same arguments detailed above with respect to the deficiencies of JP '317 are applicable to Haman.

IV. Refusal to Evaluate Claims 19 and 21-25 for Anticipation and Obviousness

The Office Action of September, 2005, refuses to examine claims 19 and 21-25, which were rejected under 35 U.S.C. §112, first and second paragraphs, in view of the prior art.

As detailed above, these claims are neither indefinite, nor in violation of the written description requirement. Moreover, the refusal in the Office Action to examine these claims in view of the prior art is in ***direct contradiction*** with MPEP §2143.03, second paragraph,

which states that "claim limitation which is considered indefinite ***cannot*** be disregarded. (MPEP §2143.03, second paragraph, emphasis added.) MPEP §2143.03 also states that if "a claim is subject to more than one interpretation, at least one of which would render the claim unpatentable over the prior art, the examiner ***should*** reject the claim as indefinite . . . and ***should*** reject the claim over the prior art based on the interpretation of the claim that renders the prior art applicable." (MPEP §2143.03, second paragraph, emphasis added.)

In any event. There are no rejections of claims 19 and 21-25 over the prior art.

CONCLUSION

Appellants respectfully request that all rejections be reversed for the reasons set forth above.

Respectfully submitted,

Date April 2, 2007

By ______________________

Martin J. Cosenza
Registration No. 48,892

Richard L. Schwaab
Registration No. 25,479

FOLEY & LARDNER LLP
Customer Number: 22428
Telephone: (202) 295-4747
Facsimile: (202) 672-5399

CLAIMS APPENDIX

1. A connecting rod comprising:

a connecting beam section serving as a main body of the connecting rod;

a big end located at a first end side of the connecting beam section;

a small end located at a second end side of the connecting beam section, the second end side being axially opposite to the first end side;

a first joining section located between the connecting beam section and the big end to connect the connecting beam section and the big end; and

a second joining section located between the connecting beam section and the small end to connect the connecting beam section and the small end;

wherein each of the first and second joining sections gradually and continuously decreases in cross sectional area toward the connecting beam section and has a strength distribution in which a strength increases with a decrease in the cross sectional area.

2. A connecting rod as claimed in Claim 1, wherein the strength distribution is based on a proportion (%) of martensite.

4. A connecting rod as claimed in Claim 2, wherein the strength distribution is formed based on a distribution in at least one of a hardening temperature and a tempering time for each of the first and second joining sections.

19. A high-strength connecting rod comprising:

a connecting beam section serving as a main body of the connecting rod, the connecting beam section having a smallest cross sectional area portion which is the smallest in cross sectional area throughout the connecting rod;

a big end located at a first end side of the connecting beam section;

a small end located at a second end side of the connecting beam section, the second end side being axially opposite to the first end side;

a first joining section located between the connecting beam section and the big end to connect the connecting beam section and the big end; and

a second joining section located between the connecting beam section and the small end to connect the connecting beam section and the small end;

wherein each of the first and second joining sections gradually and continuously decreases in cross sectional area toward the connecting beam section;

wherein a lowest fatigue strength portion which is the lowest in fatigue strength exists in at least one of the big and small ends, and a variable fatigue strength portion which varies in fatigue strength exists in each of the first and second joining sections and in the connecting beam section;

wherein a product of the cross sectional area and the fatigue strength at a cross section of each of the joining and connecting beam section is equal to or greater than a product of the cross sectional area and the fatigue strength in the smallest cross sectional area portion in the connecting beam section.

21. A high-strength connecting rod as claimed in Claim 19, wherein the high strength connecting rod is formed of a steel including, on mass basis, 0.20 to 0.43% of C, 0.05 to 2.0% of Si, 0.30 to 1.40% of Mn, less than 0.07% of P, 2.5% or less of Cr, 0.05% or less of Al and 0.005 to 0.03% of N, and at least one selected from the group consisting of

0.03 to 0.5% of V, 0.005 to 0.5% of Nb and 0.005 to 0.5% of Ti, the balance being Fe and impurities.

22. A high-strength connecting rod as claimed in Claim 19, wherein the high-strength connecting rod is formed of a steel including, on mass basis, 0.20 to 0.43% of C, 0.05 to 2.0% of Si, 0.30 to 1.40% of Mn, 0.07 to 0.15% of P, 2.5% or less of Cr, 0.05% or less of Al, 0.005 to 0.03% of N, and at least one selected from the group consisting of 0.03 to 0.5% of V, 0.005 to 0.5% of Nb and 0.005 to 0.5% of Ti, the balance being Fe and impurities.

23. A high-strength connecting rod as claimed in Claim 21, wherein the steel further includes, on mass basis, at least one selected from the group consisting of 2.0% or less of Ni, 1.0% or less of Mo, and 0.0010 to 0.0030% of B.

24. A high-strength connecting rod as claimed in Claim 21, wherein the steel further includes, on mass basis, at least one selected from the group consisting of 0.2% or less of S, 0.3% or less of Pb, 0.1% or less of Ca, and 0.3% or less of Bi.

25. A high-strength connecting rod as claimed in Claim 19, wherein the high-strength connecting rod has been subjected to shot peening.

EVIDENCE APPENDIX

No evidence is hereby submitted.

RELATED PROCEEDINGS APPENDIX

There are no related proceedings.

EXHIBIT APPENDIX I

In rejecting a claim, the examiner must set forth express findings of fact which support the lack of written description conclusion (see MPEP § 2163 for examination guidelines pertaining to the written description requirement). These findings should:

(A) Identify the claim limitation at issue; and

(B) Establish a *prima facie* case by providing reasons why a person skilled in the art at the time the application was filed would not have recognized that the inventor was in possession of the invention as claimed in view of the disclosure of the application as filed. A general allegation of "unpredictability in the art" is not a sufficient reason to support a rejection for lack of adequate written description. A simple statement such as "Appellant has not pointed out where the new (or amended) claim is supported, nor does there appear to be a written description of the claim limitation '____' in the application as filed." may be sufficient where the claim is a new or amended claim, the support for the limitation is not apparent, and Appellant has not pointed out where the limitation is supported.

When appropriate, suggest amendments to the claims which can be supported by the application's written description, being mindful of the prohibition against the addition of new matter in the claims or description. See *Rasmussen*, 650 F.2d at 1214, 211 USPQ at 326.

EXHIBIT APPENDIX II

The attached document was utilized as a reference against Appellants for the first time in the Final Office Action of September, 2005, which is where it first appears in the record.

MECHANICAL DESIGN AND SYSTEMS HANDBOOK

HAROLD A. ROTHBART, Editor-in-Chief

Dean, College of Science and Engineering
Fairleigh Dickinson University
Teaneck, New Jersey

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CONTRIBUTORS

CLAYTON H. ALLEN, Ph.D., *Senior Engineering Scientist, Bolt Beranek and Newman, Inc., Cambridge, Mass.* (Section 7, *Noise Control*)

JOHN W. AXELSON, Ph.D., *Section Chief, Packings Development, Johns Manville Corp., Research Center, Manville, N.J.* (Section 24, *Pressure Components (Seals)*)

W. H. BAIER, Ph.D., *Senior Research Engineer, Armour Research Foundation, Chicago, Ill.* (Section 29, *Belts*)

ANTONIO F. BALDO, Ph.D., *Associate Professor of Mechanical Engineering, The City University of New York, New York, N.Y.* (Section 34, *Dampers*)

PHILIP BARKAN, Ph.D., *Senior Research Engineer, General Electric Company, Switchgear and Control Division, Philadelphia, Pa.* (Section 16, *Impact*)

STANLEY J. BECKER, M.S., *Engineer, Advanced Techniques Re-entry Systems Department, General Electric Corp., Philadelphia, Pa.* (Section 23, *Shrink- and Press-fitted Assemblies*)

KARL BRUNELL, B.M.E., *Research Associate, Princeton Laboratory, American Can Co., Princeton, N.J.* (Section 26, *Power Screws*)

JOHN A. CARLSON, Ph.D., *Engineering Specialist, MRD Division, General American Transportation Corp., Niles, Ill.* (Section 2, *Computers*)

SAUL FENSTER, Ph.D., *Chairman, Department of Mechanical Engineering, Fairleigh Dickinson University, Teaneck, N.J.* (Section 1, *Mathematics*, and Section 18, *Mechanical Design*)

E. T. FORTINI, M.S., *Staff Engineer, Compugraphic Corp., Reading, Mass., and Lecturer in Mechanical Engineering, Lincoln College, Northeastern University, Boston, Mass.* (Section 19, *Fabrication Principles*)

FERDINAND FREUDENSTEIN, Ph.D., *Professor of Mechanical Engineering, Columbia University, New York, N.Y.* (Section 4, *Kinematics of Mechanisms*)

THEODORE GELA, D.Sc., *Professor of Metallurgy, Stevens Institute of Technology, Hoboken, N.J.* (Section 17, *Properties of Engineering Materials*)

HERBERT H. GOULD, M.M.E., *Engineer, Sperry Gyroscope Co., Great Neck, N.Y.* (Section 1, *Mathematics* and Section 18, *Mechanical Design*)

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Section 17

PROPERTIES OF ENGINEERING MATERIALS

By

THEODORE GELA, D.Sc., *Professor of Metallurgy, Stevens Institute of Technology, Hoboken, N.J.*

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17.1. MATERIAL-SELECTION CRITERIA IN ENGINEERING DESIGN

The selection of materials for engineering components and devices depends upon a knowledge of material properties and behavior in particular environmental states. Although a criterion for the choice of material in critically designed parts relates to the performance in a field test, it is usual in preliminary design to use appropriate data obtained from standardized tests. The following considerations are important in material selection:

1. Elastic properties
   a. Stiffness and rigidity
2. Plastic properties
   a. Yield conditions, stress-strain relations, and hysteresis

3. Time-dependent properties
   a. Elastic phenomenon (damping capacity), creep, relaxation, and strain-rate effect
4. Fracture phenomenon
   a. Crack propagation, fatigue, and ductile to brittle transition
5. Thermal properties
   a. Thermal expansion, thermal conductivity, and specific heat
6. Chemical interactions with environment
   a. Oxidation, corrosion, and diffusion

It is good design practice to analyze the conditions under which test data were obtained and to use the data most pertinent to anticipated service conditions.

The challenge that an advancing technology imposes on the engineer, in specifying treatments to meet stringent material requirements, implies a need for a basic approach which relates properties to structure in metals. As a consequence of the mechanical, thermal, and metallurgical treatments of metals, it is advantageous to explore, for example, the nature of induced internal stresses as well as the processes of stress relief. Better material performance may ensue when particular treatments can be specified to alter the structure in metals so that the likelihood of premature failure in service is lessened. Some of the following concepts are both basic and important:

1. Lattice structure of metals
   a. Imperfections, anisotropy, and deformation mechanisms
2. Phase relations in alloys
   a. Equilibrium diagrams
3. Kinetic reactions in the solid state
   a. Heat-treatment by nucleation and by diffusionless processes, precipitation hardening, diffusion, and oxidation
4. Surface treatments
   a. Chemical and structural changes in carburizing, nitriding, and localized heating
5. Metallurgical bonds
   a. Welded and brazed joints.

17.2. STRENGTH PROPERTIES—TENSILE TEST AT ROOM TEMPERATURE

The yield strength determined by a specified offset, 0.2 per cent strain, from a stress-strain diagram is an important and widely used property for the design of statically loaded members exhibiting elastic behavior. This property is derived from a test in which the following conditions are normally controlled: surface condition of standard specimen is specified; load is axial; the strain rate is low, i.e., about 10^{-3} in./in./sec; and grain size is known. Appropriate safety factors are applied to the yield strength to allow for uncertainties in the calculated stress and stress-concentration factors and for possible overloads in service. Since relatively small safety factors are used in critically stressed aircraft materials, a proof stress at 0.01 per cent strain offset is used because this more nearly approaches the proportional limit for elastic behavior in the material. A typical stress-strain plot from a tensile test is shown in Fig. 17.1 indicating the elastic and plastic behaviors. In order to effect more meaningful comparisons in design strength properties among materials having different specific gravities, the strength property can be divided by the specific gravity, giving units of psi per pound per cubic inch.

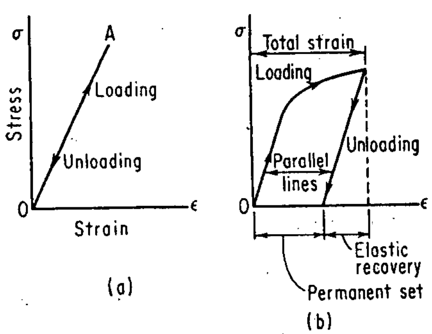

FIG. 17.1. Portions of tensile stress σ–strain E curves in metals.[1] (a) Elastic behavior. (b) Elastic and plastic behaviors.

The modulus of elasticity is a measure of the stiffness or rigidity in a material. Values of the modulus normally are not exactly determined quantities, and typical values are commonly reported for a given material. When a material is selected on the basis of a high modulus, the tendency toward whip and vibration in shaft or rod applications is reduced. These effects can lead to uneven wear. Furthermore the modulus assumes particular importance in the design of springs and diaphragms, which necessitate a definite degree of motion for a definite load. In this connection, selection of a higher-modulus material can lead to a thinner cross section.

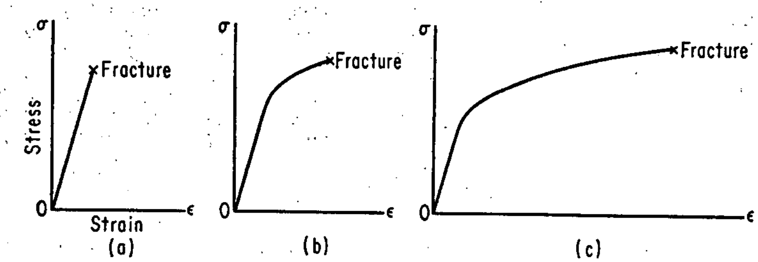

FIG. 17.2. The effects of treatments on tensile characteristics of a metal.[1] (a) Perfectly brittle (embrittled)—all elastic behavior. (b) Low ductility (hardened)—elastic plus plastic behaviors. (c) Ductile (softened)—elastic plus much plastic behaviors.

The ultimate tensile strength and the ductility, per cent elongation in inches per inch or per cent reduction in area at fracture are other properties frequently reported from tensile tests. These serve as qualitative measures reflecting the ability of a material in deforming plastically after being stressed beyond the elastic region. The strength properties and ductility of a material subjected to different treatments can vary widely. This is illustrated in Fig. 17.2. When the yield strength is raised by treatment to a high value, i.e., greater than two-thirds of the tensile strength, special concern should be given to the likelihood of tensile failures by small overloads in service. Members subjected solely to compressive stress may be made from high-yield-strength materials which result in weight reduction.

When failures are examined in statically loaded tensile specimens of circular section, they can exhibit a cup-and-cone fracture characteristic of a ductile material or on the other extreme a brittle fracture in which little or no necking down is apparent. Upon loading the specimen to the plastic region, axial, tangential, and radial stresses are induced. In a ductile material the initial crack forms in the center where the triaxial stresses become equally large, while at the surface the radial component is small and the deformation is principally by biaxial shear. On the other hand, an embrittled material exhibits no such tendency for shear and the fracture is normal to the loading axis. Some types of failures in round tensile specimens are shown in Fig. 17.3.

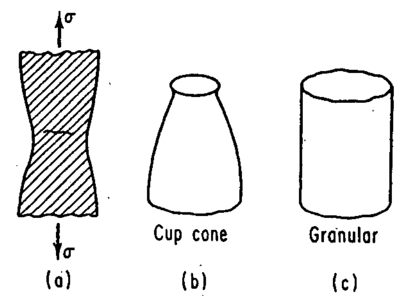

FIG. 17.3. Typical tensile-test fractures.[1] (a) Initial crack formation. (b) Ductile material. (c) Brittle material.

The properties of some wrought metals presented in Table 17.1 serve to show the significant differences relating to alloy content and treatment. Article 17.14 gives more information.

The tensile properties of metals are dependent upon the rate of straining, as shown for aluminum and copper in Fig. 17.4, and are significantly affected by the temperature as shown in Fig. 17.5. For high-temperature applications it is important to base

Table 17.1. Room-temperature Tensile Properties for Some Wrought Metals

Metal	Condition	Ultimate tensile σ_{ult}, psi	Yield strength σ_y, psi	% elongation	Modulus of elasticity, psi	Density, lb/cu in.
Aluminum (pure)	Annealed	13,000	5,000	35	10,000,000	0.098
7075T6	Heat-treated	76,000	67,000	11	10,400,000	0.101
Copper (pure)	Annealed	32,000	10,000	45	17,000,000	0.321
Cu-Be(2%)	Heat-treated	200,000	150,000	2	19,000,000	0.297
Magnesium	Annealed	33,000	18,000	17	6,500,000	0.064
Mg-Al(8.5)A780A.	Strain relieved	44,000	31,000	18	6,500,000	0.065
Nickel (pure)	Annealed	65,000	20,000	40	30,000,000	0.321
K Monel	Heat-treated	190,000	140,000	5	....	0.306
Titanium (pure)	Annealed	59,000	40,000	28	15,000,000	0.163
Ti-Al(6)-V(14)α-β.	Heat-treated	170,000	150,000	7	15,000,000	0.163

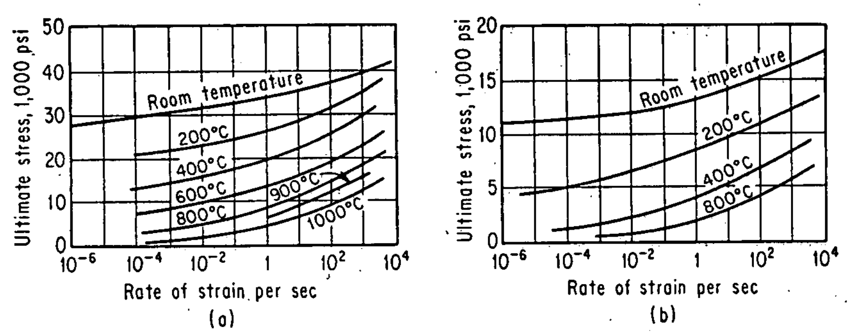

FIG. 17.4. Effects of strain rates and temperatures on tensile-strength properties of copper and aluminum.[1] (a) Copper. (b) Aluminum.

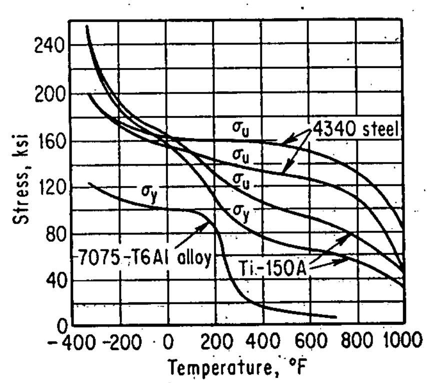

FIG. 17.5. Effects of temperatures on tensile properties.
σ_u = ultimate tensile strength
σ_y = yield strength

design on different criteria, notably the stress-rupture and creep characteristics in metals, both of which are also time-dependent phenomena. The use of metals at low temperatures requires a consideration of the possibility of brittleness, which can be measured in the impact test.

17.3. ATOMIC ARRANGEMENTS IN PURE METALS—CRYSTALLINITY

The basic structure of materials provides information upon which properties and behavior of metals may be generalized so that selection can be based on fundamental considerations. A regular and periodic array of atoms (in common metals whose atomic diameters are about one hundred-millionth of an inch) in space, in which a unit cell is the basic structure, is a fundamental characteristic of crystalline solids. Studies of these structures in metals lead to some important considerations of the behaviors

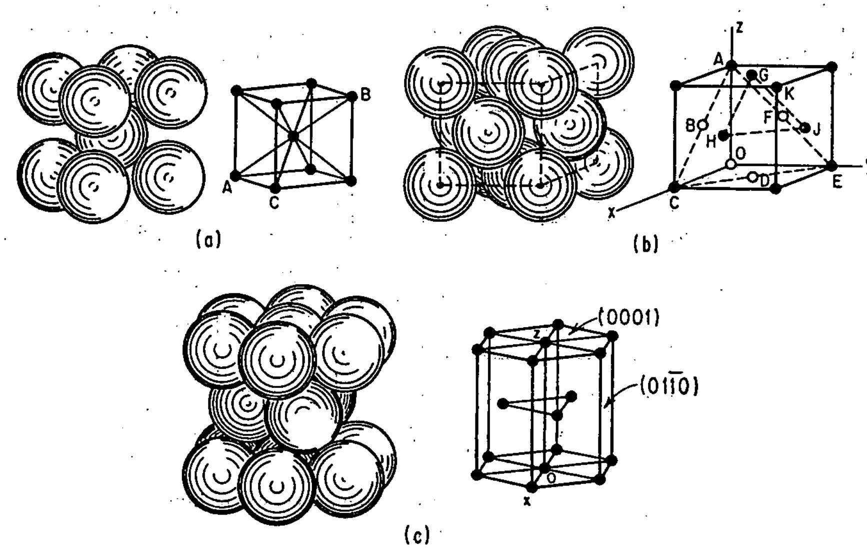

FIG. 17.6. Cell structure. (a) Body-centered cubic (b.c.c.) unit cell structure. (b) Face-centered cubic (f.c.c.) unit cell structure. (c) Hexagonal close-packed (h.c.p.) unit cell structure.

in response to externally applied forces, temperature changes, as well as applied electrical and magnetic fields.

The body-centered cubic (b.c.c.) cell shown in Fig. 17.6a is the atomic arrangement characteristic of αFe, W, Mo, Ta, βTi, V, and Nb. It is among this class of metals that transitions from ductile to brittle behavior as a function of temperature are significant to investigate. This structure represents an atomic packing density where about 66 per cent of the volume is populated by atoms while the remainder is free space. The elements Al, Cu, γFe, Ni, Pb, Ag, Au, and Pt have a closer packing of atoms in space constituting a face-centered cubic (f.c.c.) cell shown in Fig. 17.6b. Characteristic of these are ductility properties which in many cases extend to very low temperatures. Another structure, common to Mg, Cd, Zn, αTi, and Be, is the hexagonal close-packed (h.c.p.) cell in Fig. 17.6c. These metals are somewhat more difficult to deform plastically than the materials in the two other structures cited above.

It is apparent, from the atomic arrays represented in these structures, that the closest approach of atoms can vary markedly in different crystallographic directions. Properties in materials are anisotropic when they show significant variations in different

Table 17.2. Examples of Anisotropic Properties in Single Crystals

Property	Material and structure	Properties relation	Reference
Elastic modulus E in tension.........	αFe(b.c.c.)	$E_{(AB)} \sim 2.2E_{(AC)}$	Fig. 17.6*a*
Elastic modulus G in shear..........	Ag (f.c.c.)	$G_{(OC)} \sim 2.3G_{(OK)}$	Fig. 17.6*b*
Magnetization....................	αFe (b.c.c.)	Ease of magnetization	Fig. 17.7
Thermal expansion coefficient — α....	Zn (h.c.p.)	$\alpha_{(OZ)} \sim 4\alpha_{(OA)}$	Fig. 17.6*c*

directions. Such tendencies are dependent on the particular structure and can be especially pronounced in single crystals (one orientation of the lattices in space). Some examples of these are given in Table 17.2. When materials are processed so that their final grain size is large (each grain represents one orientation of the lattices) or

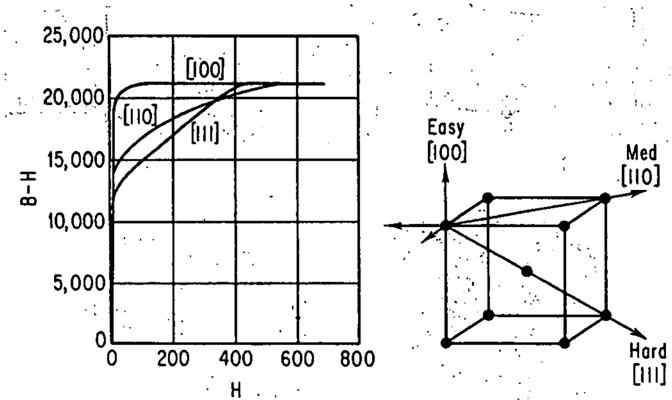

FIG. 17.7. Magnetic anisotropy in a single crystal of iron.[2]

$$I = \frac{B - H}{4\pi}$$

where I = intensity of magnetization
B = magnetic induction, gauss
H = field strength, oersteds

that the grains are preferentially oriented, as in extrusions, drawn wire, rolled sheet, sometimes in forgings and castings, special evaluation of anisotropy should be made. In the event that directional properties influence design considerations, particular attention must be given to metallurgical treatments which may control the degree of anisotropy. The magnetic anisotropy in a single crystal of iron is shown in Fig. 17.7.

17.4. PLASTIC DEFORMATION OF METALS

When metals are externally loaded past the elastic limit, so that permanent changes in shape occur, it is important to consider the induced internal stresses, property changes, and the mechanisms of plastic deformation. These are matters of practical consideration in the following: materials that are to be strengthened by cold work, machining of cold-worked metals, flow of metals in deep-drawing and impact extrusion operations, forgings where the grain flow patterns may affect the internal soundness, localized surface deformation to enhance fatigue properties, and cold working of some magnetic materials. Experimental studies provide the key by which important phenomena are revealed as a result of the plastic-deformation process. These studies

indicate some treatments that may be employed to minimize unfavorable internal-stress distributions and undesirable grain-orientation distributions.

Plastic deformation in metals occurs by a glide or slip process along densely packed planes fixed by the particular lattice structure in a metal. Therefore, an applied load is resolved as a shear stress, on those particular glide elements (planes and directions) requiring the least amount of deformation work on the system. An example of this

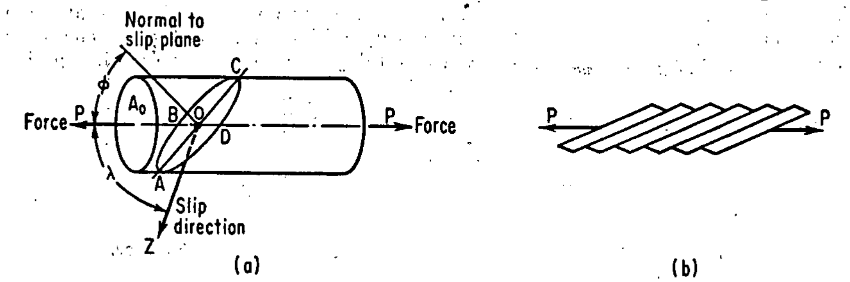

FIG. 17.8. Slip deformation in single crystals. (*a*) Resolved shear stress = $P/A_0 \cos\phi \cos\lambda$. $ABCD$ is plane of slip. OZ is slip direction. (*b*) Sketch of single crystal after yielding.

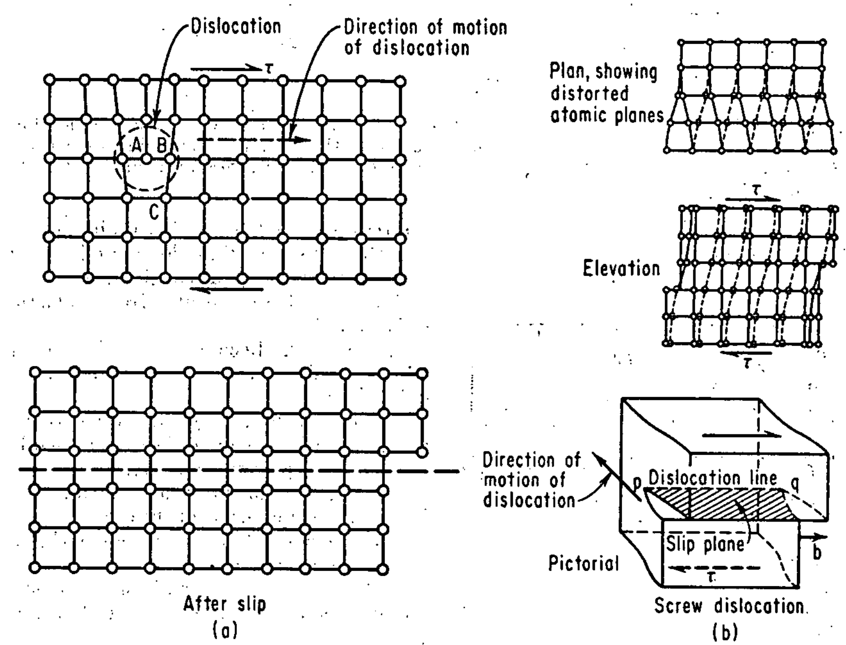

FIG. 17.9. Edge and screw dislocations as types of imperfections in metals.[2] (*a*) Edge dislocation. (*b*) Screw dislocation.

deformation process is shown in Fig. 17.8. Face-centered cubic structured metals, such as Cu, Al, and Ni, are more ductile than the hexagonal structured metals like Mg, Cd, and Zn at room temperature because in the f.c.c. structure there are four times as many possible slip systems as in a hexagonal structure. Slip is initiated at much lower stresses in metals than theoretical calculations based on a perfect array of atoms would indicate. In real crystals there are inherent structural imperfections termed dislocations (atomic misfits) as shown in Fig. 17.9, which account for the observed

yielding phenomenon in metals. In addition, dislocations are made mobile by mechanical and thermal excitations and they can interact to result in strain hardening of metals by cold work. Strength properties can be increased while the ductility is decreased in those metals which are amenable to plastic deformation. Cold working of pure metals and single-phase alloys provides the principal mechanism by which these may be hardened.

The yielding phenomenon is more nonhomogeneous in polycrystalline metals than in single crystals. Plastic deformation in polycrystalline metals initially occurs only in those grains in which the lattice axes are suitably oriented relative to the applied

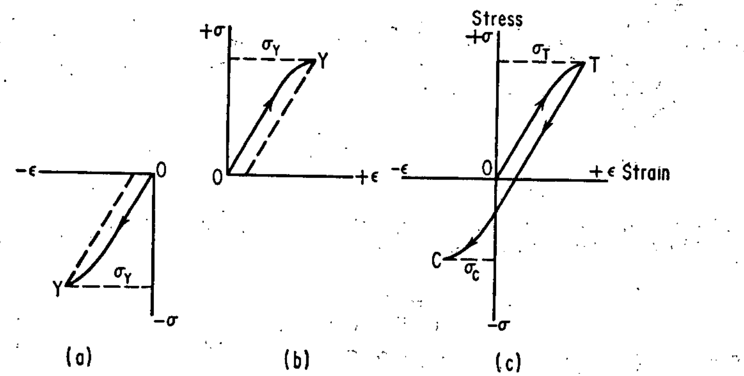

FIG. 17.10. The Bauschinger effect. (a) Compression. (b) Tension. The application of a compressive stress (a) or a tensile stress (b) results in the same value of yield strength σ_Y. (c) Stress reversal. A reversal of stress $O \rightarrow T \rightarrow C$ results in different values of tensile and compressive yield strengths; $\sigma_T \neq \sigma_C$.

load axis, so that the critically resolved shear stress is exceeded. Other grains rotate and are dependent on the orientation relations of the slip systems and load application; these may deform by differing amounts.

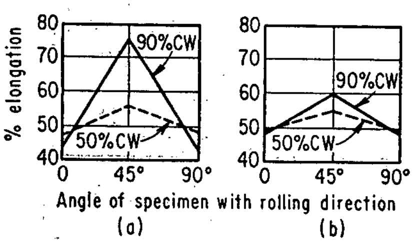

FIG. 17.11. Directionality in ductility in cold-worked and annealed copper sheet.[1] (a) Annealed at 1470°F. (b) Annealed at 750°F. The variation in ductility with direction for copper sheet is dependent on both the annealing temperature and the amount of cold work (per cent CW) prior to annealing.

As matters of practical considerations the following effects result from plastic deformation:

1. Materials become strain-hardened and the resistance to further strain hardening increases.

2. The tensile and yield strengths increase with increasing deformation, while the ductility properties decrease.

3. Macroscopic internal stresses are induced in which parts of the cross section are in tension while other regions have compressive elastic stresses.

4. Microscopic internal stresses are induced along slip bands and grain boundaries.

5. The grain orientations change with cold work so that some materials may exhibit different mechanical and physical properties in different directions.

The Bauschinger effect in metals is related to the differences in the tensile and compressive yield-strength values, as shown at σ_T and σ_C in Fig. 17.10 when a ductile metal undergoes stress reversal. This change in polycrystalline metals is the result of the nonuniform character of deformation and the different pattern of induced macrostresses. These grains, in which the induced macrostresses are compressive, will yield at lower values upon the application of a reversed compressive stress because

they are already part way toward yielding. This effect is encountered in cold-rolled metals where there is lateral contraction together with longitudinal elongation; this accounts for the decreased yield strength in the lateral direction compared with the increased longitudinal yield strength.

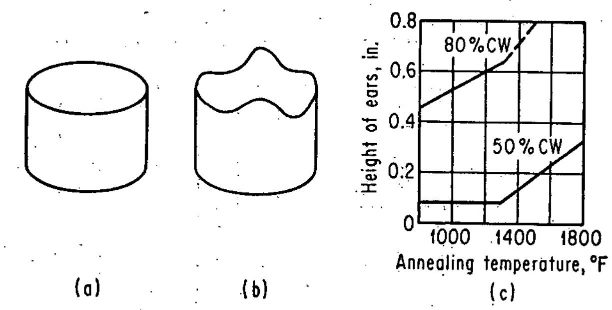

FIG. 17.12. The earing tendencies in cup deep-drawn from sheet. (a) Uniform flow, nonearing. (b) Eared cup, the result of nonuniform flow. (c) Height of ears in deep-drawn copper cups related to annealing temperature and amount of cold work.

The control of metal flow is important in deep-drawing operations performed on sheet metal. It is desirable to achieve a uniform flow in all directions. Cold-rolling sheet metal produces a structure in which the grains have a preferred orientation. This characteristic can persist, even though the metal is annealed (recrystallized), resulting in directional properties as shown in Fig. 17.11. A further consequence of this directionality, associated with the deep-drawing operation, is illustrated in Fig. 17.12. The important factors, involved with the control of earing tendencies, are the fabrication practices of the amount of cold work in rolling and duration and temperatures of annealing. When grain textural problems of this kind are encountered they can be studied by X-ray diffraction techniques and reasonably controlled by the use of optimum cold-working and annealing schedules.

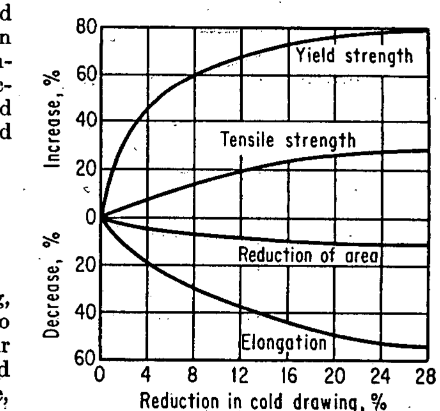

FIG. 17.13. Effect of cold drawing on the tensile properties of steel bars of up to 1 in. cross section having tensile strength of 110,000 psi or less before cold drawing.[3]

17.5. PROPERTY CHANGES RESULTING FROM COLD-WORKING METALS

Cold-working metals by rolling, drawing, swaging, and extrusion is employed to strengthen them and/or to change their shape by plastic deformation. It is used principally on ductile metals which are pure, single-phase alloys and for other alloys which will not crack upon deformation. The increase in tensile strength accompanied by the decrease in ductility characteristic of this process is shown in Fig. 17.13. It is to be noted, especially from the yield-strength curve, that the largest rates of change occur during the initial amounts of cold reduction.

The variations in the macrostresses induced in a cold-drawn bar, illustrated in Fig. 17.14a, show that tensile stresses predominate at the surface. The equilibrium state of macrostresses throughout the cross section is altered by removing the surface layers in machining, the result of which may be warping in the machined part. It

may be possible, however, to stress-relieve cold-worked metals, which generally have better machinability than softened (annealed) metals, by heating below the recrystallization temperature. A typical alteration in the stress distribution, shown in Fig. 17.14*b*, is achieved so that the warping tendencies on machining are reduced, without decreasing the cold-worked strength properties. This stress-relieving treatment may also inhibit season cracking in cold-worked brasses subjected to corrosive environments

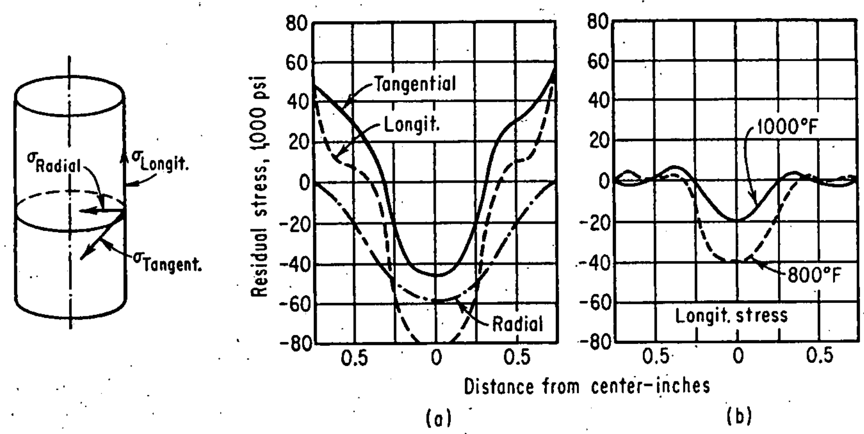

FIG. 17.14. Residual stress.[3] (*a*) In a cold-drawn steel bar 1½ in. in diameter 20 per cent cold drawn, 0.45C steel. (*b*) After stress-relieving bar.

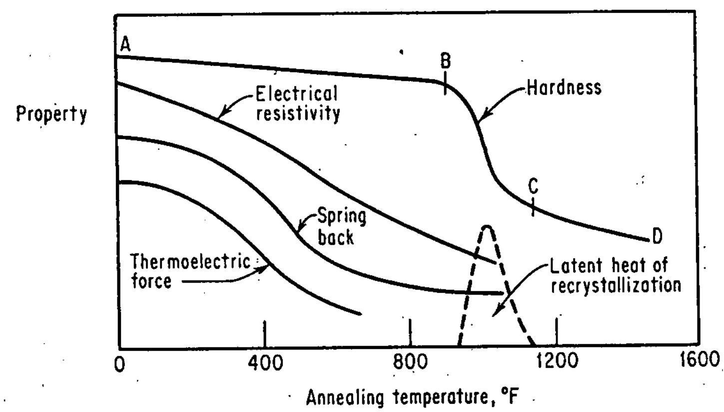

FIG. 17.15. The property changes in 95 per cent cold-worked iron with heating temperatures (1 hr). The temperature intervals:[4] $A \rightarrow B$, stress relieval, $B \rightarrow C$, recrystallization, and $C \rightarrow D$, grain growth, signify the important phenomena occurring.

containing amines. Since stressed regions, in a metal, are more anodic (i.e., go into solution more readily) than unstressed regions, it is often important to consider the relieving of stresses so that the designed member is not so likely to be subjected to localized corrosive attack.

Changes in electrical resistivity, elastic springback, and thermoelectric force, resulting from cold work, can be altered by a stress-relieval treatment, in a temperature range from *A* to *B*, as shown in Fig. 17.15. However, the grain flow pattern (preferred orientation) produced by cold working can be changed only by heating the metal to a temperature at which recrystallized stress-free grains will form.

Residual tensile stresses at the surface of a metal promote crack nucleation in the fatigue of metal parts. The use of a localized surface deformation treatment by shot peening, which induces compressive stresses in the surface fibers, offers the likelihood of improvement in fatigue and corrosion properties in alloys. Shot peening a forging flash line in high-strength aluminum alloys used in aircraft may also lessen the tendency toward stress-corrosion cracking. The effectiveness of this localized surface-hardening treatment is dependent on both the nature of surface discontinuities formed by shot peening and the magnitude of compressive stresses induced at the surface.

17.6. THE ANNEALING PROCESS

Metals are annealed in order to induce softening for further deformation, to relieve residual stresses, to alter the microstructure and, in some case after electroplating,

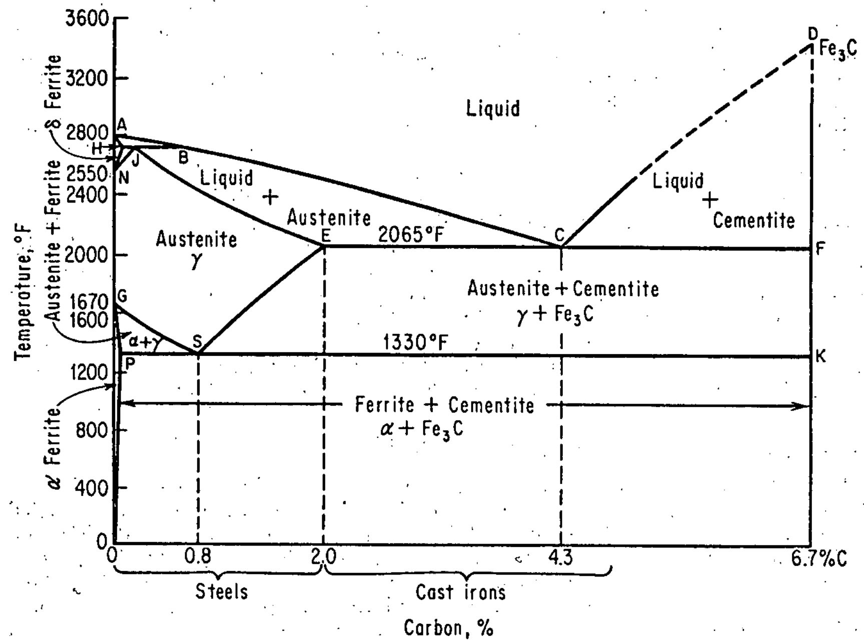

FIG. 17.16. The iron-carbon phase diagram.[4]

to expel, by diffusion, gases entrapped in the lattice. The process of annealing, the attaining of a strain-free recrystallized grain structure, is dependent mainly on the temperature, time, and the amount of prior cold work. The temperature indicated at *C* in Fig. 17.15 results in the complete annealing after 1 hr of the 95 per cent cold-worked iron. Heating beyond this temperature causes grains to grow by coalescence, so that the surface-to-volume ratio of the grains decreases together with decreasing the internal energy of the system. As the amount of cold work (from the originally annealed state) decreases, the recrystallization temperature increases and the recrystallized grain size increases. When a metal is cold-worked slightly (less than 10 per cent) and subsequently annealed, an undesirable roughened surface forms because of the abnormally large grain size (orange-peel effect) produced. These aspects of grain-size control in the annealing process enter in material specifications.

The annealing of iron-carbon-base alloys (steels) is accomplished by heating alloys of eutectoid and hypoeutectoid compositions (0.8 per cent C and less in plain carbon steels) to the single-phase region, austenite, as shown in Fig. 17.16 above the transition

line GS; and for hypereutectoid alloys (0.8 to 2.0 per cent C) between the transition lines SK and SE in Fig. 17.16; followed by a furnace cool at a rate of about 25°F per hour to below the eulectoid temperature SK. In the annealed condition, a desirable distribution of the equilibrium phases is thereby produced. A control of the microstructure is manifested by this process in steels. Grain-size effects are principally controlled by the high-temperature treatment, grain sizes increasing with increasing temperatures, and in some cases minor impurity additions like vanadium inhibit grain coarsening to higher temperatures. These factors of grain-size control enter into the considerations of hardening steels by heat-treatment.

The control of the atmosphere in the annealing furnace is desirable in order to prevent gas-metal attack. Moisture-free neutral atmospheres are used for steels which oxidize readily. When copper and its alloys contain oxygen, as oxide, it is necessary to keep the hydrogen content in the atmosphere to a minimum. At temperatures lower than 900°F, the hydrogen should not exceed 1 per cent, and as the temperature is increased the hydrogen content should be reduced in order to prevent hydrogen embrittlement. In nickel and its alloys the atmosphere must be free from sulfur and slightly reducing by containing 2 per cent or more of CO. Some aluminum alloys containing magnesium are affected by high-temperature oxidation in annealing (and heat-treatment) and therefore require atmosphere control.

It is a characteristic property that strengths in all metals decrease with increasing temperatures. The coalescence of precipitate particles is one factor involved; so that material specifications for high-temperature use are concerned with alloy compositions that form particles having lower solubility and lower mobility. A second factor is concerned with the mobility of dislocations which increases at higher temperatures. Since strain hardening is reasoned to be due to the interaction of dislocations, then by the proper additions of solid-solution alloying elements that impede dislocations, resistance to softening will increase at the high temperature. The recrystallization temperature of iron is raised by the addition of 1 atomic per cent of Mn, Cr, V, W, Cb, Ta in the same order in which the atomic size of the alloying element differs from that of iron. The practical implications of these basic atomic considerations are important in selecting metals for high-temperature service.

17.7. THE PHASE DIAGRAM AS AN AID TO ALLOY SELECTION

Phase diagrams, which are determined experimentally and are based upon thermodynamic principles, are temperature-composition representations of slowly cooled alloys (annealed state). They are useful for predicting property changes with composition and selecting feasible fabrication processes. Phase diagrams also indicate the possible response of alloys to hardening by heat-treatment. Shown on these diagrams are first-order phase transitions and the phases present. In two-phase regions, the compositions of each phase are shown on the phase boundary lines and the relative amounts of each phase present can be determined by a simple lever relation at a given temperature.

The particular phases that are formed in a system are governed principally by the physical interactions of valency electrons in the atoms and secondarily by atomic-size factors. When two different atoms in the solid state exist on, or where one is in, an atomic lattice, the phase is a solid solution (e.g., γ austenite phase in Fig. 17.16) analogous to a miscible liquid solution. When the atoms are strongly electropositive and strongly electronegative to one another, an intermetallic compound is formed (e.g., Fe_3C, cementite). The two atoms are electronically indifferent to one another and a phase mixture issues (e.g., $\alpha + Fe_3C$) analogous to the immiscibility of water and oil.

The thermodynamic criteria for a first-order phase change, indicated by the solid lines on the phase diagram, are that, at the transition temperature, (1) the change in Gibbs's free energy for the system is zero; (2) there is a discontinuity in entropy (a latent heat of transformation and a discontinuous change in specific heat); and (3) there is a discontinuous change in volume (a dilational effect).

In the selection of alloys for sound castings, particular attention is given that part

of the system where the liquidus line ($ABCD$) goes through a minimum. For alloys between the composition limits of $E \rightarrow F$, a eutectic reaction occurs at 2065°F such that

$$\text{liq } C = \gamma + Fe_3C$$

It is for this reason in the iron-carbon system that cast irons are classified as having carbon contents greater than 2 per cent. For purposes of controlling grain size, obtaining sound castings free from internal porosities (blowholes) and internal shrinkage cavities, and possessing good mold-filling characteristics, alloys and low-melting solutions are chosen near the eutectic composition (i.e., at C). Aluminum-silicon die-casting alloys have a composition of about 11 per cent silicon near the eutectic composition. Special considerations need be given to the properties and structures in cast irons because the Fe_3C phase is thermodynamically unstable and decomposition to graphite (in gray cast irons) may result.

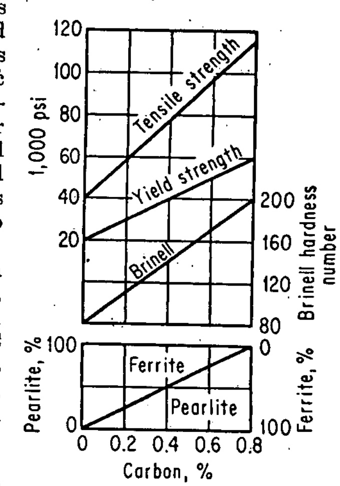

FIG. 17.17. Relation of mechanical properties and structure to carbon content of slowly cooled carbon steels.[4]

The predominant phase-diagram characteristic in steels is the eutectoid reaction, in the solid state, along GSE where $\gamma_s = \alpha + Fe_3C$ (pearlite) at 1330°F. Steels are therefore classified as alloys in the Fe-C system having a carbon content less than 2.0 per cent C; and furthermore, according to their applications, compositions are designated as hypoeutectoid ($C < 0.8$ per cent), eutectoid ($C = 0.8$ per cent), and hypereutectoid ($C < 2$ per cent > 0.8 per cent). Since the slowly cooled room-temperature structures of steels contain a mechanical aggregate of the ferrite and Fe_3C-cementite phases, the property relations vary linearly as shown in Fig. 17.17. The ductility decreases with increasing carbon contents.

Some important characteristics of the equilibrium phases in steels are:

Phase	*Characteristics*
α ferrite	Low C solubility (less than 0.03%) body-centered cubic, ductile and ferromagnetic below 1440°F
Fe_3C, cementite	Intermetallic compound, orthorhombic, hard, brittle, and fixed composition at 6.7% C
γ austenite	Can dissolve up to 2% C in solid solution, face-centered cubic, nonmagnetic, and in this region annealing, hardening, forging, normalizing, and carburizing processes take place

Low-carbon alloys can be readily worked by rolling, drawing, and stamping because of the predominant ductility of the ferrite. Wires for suspension cables having a carbon content of about 0.7 per cent are drawn at about 1100°F (patenting) because of the greater difficulty, in room-temperature deformation, caused by the presence of a relatively large amount of the brittle Fe_3C phase.

Extensive substitutional solid-solution alloys form in binary systems when they have similar chemical characteristics and atomic diameters in addition to having the same lattice structure. Such alloys include copper-nickel (monel metal being a commercially useful one), chromium-molybdenum, copper-gold, and silver-gold (jewelry alloys). The phase diagram and the equilibrium-property changes for this system are shown in Fig. 17.18a. Each pure element is strengthened by the addition of the other whereby the strongest alloy is at an equal atom concentration. There are no first-order phase changes up to the start of melting (the solidus line EHG); so that these are not hardened by heat-treatment but only by cold work. The electrical conductivity decreases from each end of the composition axis. Because of the presence of but one

phase, these alloys are selected for their resistance to electrochemical corrosion. High-temperature-service metals are alloys which have essentially a single-phase solid solution with minor additions of other elements to achieve specific effects.

Another important system is one in which there are present regions of partial solid solubility as shown in Fig. 17.18*b* together with equilibrium-property changes. An important consideration in the selection of alloys containing two or more phases is that galvanic-corrosion attack may occur when there exists a difference in the electromotive potential between the phases in the environmental electrolyte. Sacrificial galvanic protection of the base metal in which the coating is more anodic than the base metal is used in zinc-plating iron-base alloys (galvanizing alloys). The intimate mechanical mixture of phases which are electrochemically different may result in pitting corrosion, or even more seriously, intergranular corrosion may result if the alloy is improperly treated by causing localized precipitation at grain boundaries.

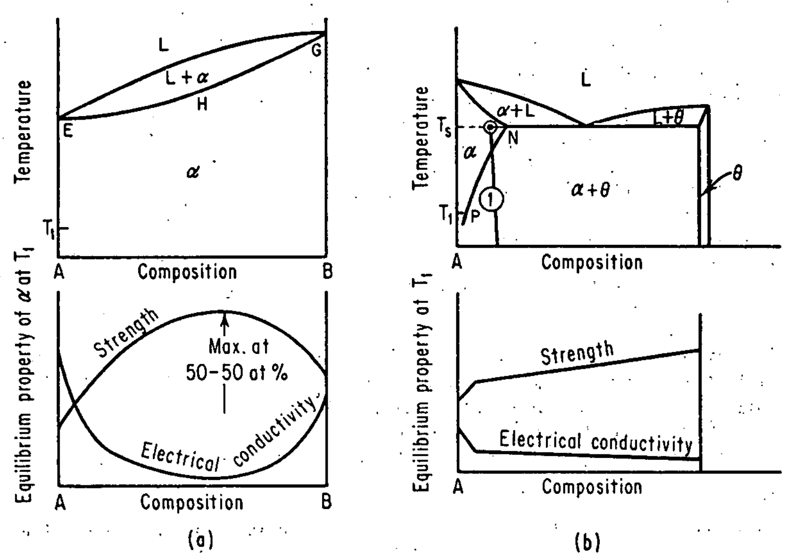

FIG. 17.18. Binary systems.[4] (*a*) Complete solid-solubility phase diagram. (*b*) Partial solid-solubility part of phase diagram. α is a substitutional solid solution, a phase with two different atoms on the same lattice. In the AlCu system θ is an intermediate phase (precipitant) having a composition nominally of $CuAl_2$.

Heat-treatment by a precipitation-hardening process is indeed an important strengthening mechanism in particular alloys such as the aircraft aluminum-base, copper-beryllium, magnesium-aluminum, and alpha-beta titanium alloys (Ti, Al, and V). In these alloys a distinctive feature is that the solvus line *NP* in Fig. 17.18*b* shows decreasing solid solubility with decreasing temperature. This in general is a necessary, but not necessarily sufficient, condition for hardening by precipitation since other thermodynamic conditions as well as coherency relations between the precipitated phases must prevail. The sequence of steps for this process is as follows: An alloy is solution heat-treated to a temperature T_s, rapidly quenched so that a metastable supersaturated solid solution is attained, and then aged at experimentally determined temperature-time aging treatments to achieve desired mechanical properties. This is the principal hardening process for those particular nonferrous alloys (including Inconels) which can respond to a precipitation-hardening process.

The engineer is frequently concerned with the strength-to-density ratio of materials and its variation with temperature. A number of materials are compared on this

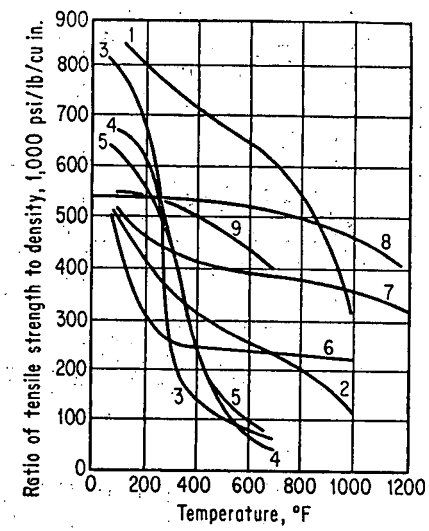

FIG. 17.19. Approximate comparison of materials on a strength-weight basis from room temperature to 1000°F.[6]

1. T_1 – 8Mn
2. 9990 T_1
3. 75S – T6Al
4. 24S – T4Al
5. AZ31A Mg
6. Annealed stainless steel
7. Half-hard stainless steel
8. Inconel X
9. Glass-cloth laminate

basis in Fig. 17.19 in which the alloys designated by curves 1, 3, 4, 5, and 8 are heat-treatable nonferrous alloys.

17.8. HEAT-TREATMENT CONSIDERATIONS FOR STEEL PARTS

The heat-treating process for steel involves heating to the austenite region where the carbon is soluble, cooling at specific rates, and tempering to relieve some of the stress which results from the transformation. Some important considerations involved in specifying heat-treated parts are strength properties, warping tendencies, mass effects (hardenability), fatigue and impact properties, induced transformation stresses, and the use of surface-hardening processes for enhanced wear resistance. Temperature and time factors affect the structures issuing from the decomposition of austenite; for a eutectoid steel (0.8 per cent C) they are:

Decomposition product from γ	Structure	Mechanism	Temp. range, °F
Pearlite........	Equilibrium ferrite + Fe_3C	Nucleation; growth	1300–1000
Bainite........	Nonequilibrium ferrite + carbide	Nucleation; growth	1000–450
Martensite.....	Supersaturated tetragonal lattice	Diffusionless	M_s(450 + lower)

The tensile strength of a slowly cooled (annealed) eutectoid steel containing a coarse pearlite structure is about 120,000 psi. To form bainite, the steel must be cooled rapidly enough to escape pearlite transformation and must be kept at an intermediate temperature range to completion, from which a product having a tensile

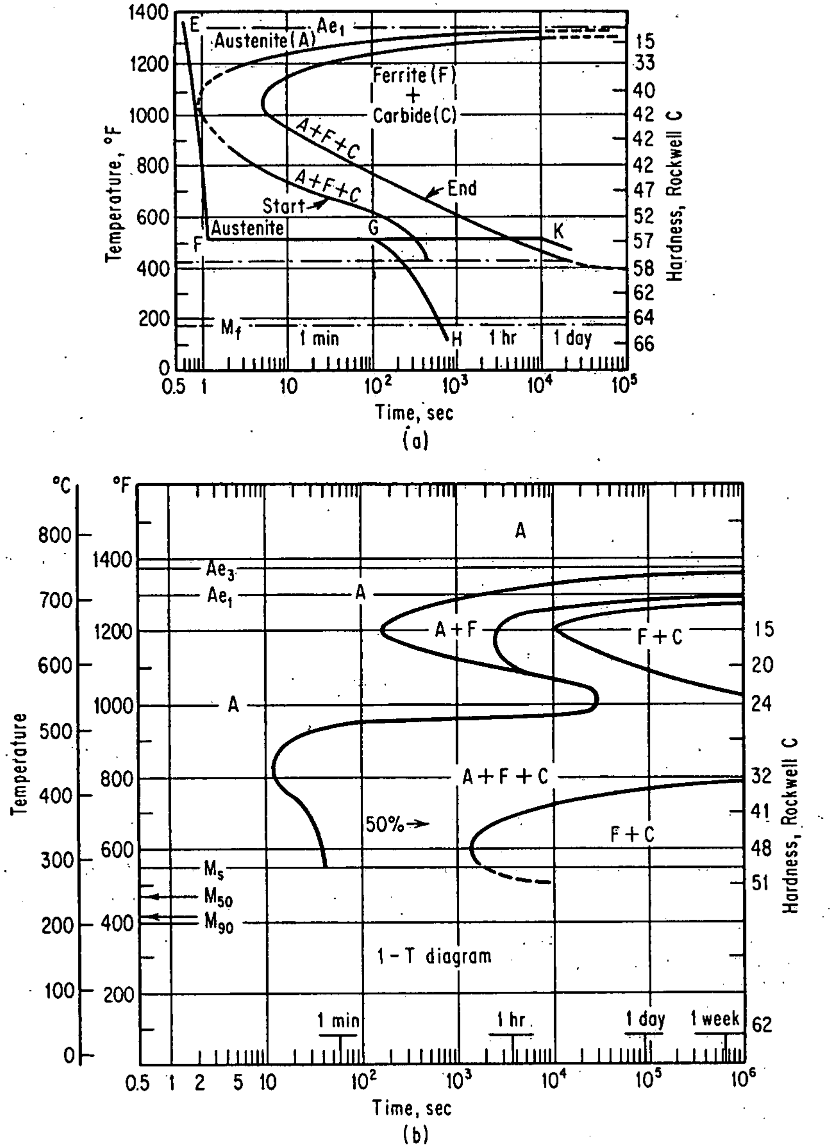

Fig. 17.20. Isothermal transformation diagram.[5] (a) Eutectoid carbon steel. (b) SAE 4340 steel.

M_S = start of martensite temperature
M_f = finish of martensite temperature
$EFGH$ = martempering (follow by tempering)
EFK = austempering

A—Austenite; *F*—Ferrite; *C*—Carbide
M_s and M_f—temperatures for start and finish of Martensile transformation
M_{50} and M_{90}—temperatures for 50 % and 90 % Martensile transformation

strength of about 250,000 psi can be formed. Martensite, the hardest and most brittle product, forms independently of time by quenching rapidly enough to escape higher-temperature transformation products. The carbon atoms are trapped in the martensite, causing its lattice to be highly strained internally; its tensile strength is in excess of 300,000 psi. Isothermal transformation characteristics of all steels show the temperature-time and transformation products as in Fig. 17.20, where the lines indicate the start and end of transformation. On the temperature-time coordinates involved cooling curves can be superimposed, which show that, for a 1-in. round water-quenched specimen, mixed products will be present. The outside will be martensite and the middle sections will contain pearlite. Alloying elements are added to steels principally to retard pearlite transformation either so that less drastic quenching media can be used or to ensure more uniform hardness throughout. This retardation is shown in Fig. 17.20*b* for a SAE 4340 steel containing alloying additions of Ni, Cr, or Mo and 0.4 per cent C.

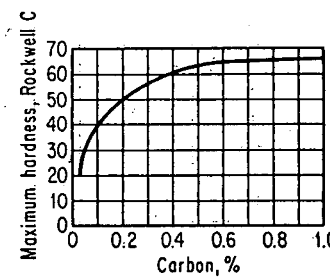

Fig. 17.21. Relation of maximum attainable hardness of quenched steels to carbon content.[7]

The carbon content in steels is the most significant element upon which selection for the maximum attainable hardness of the martensite is based. This relation is shown in Fig. 17.21. Since the atomic rearrangements involved in the transformation from the face-centered-cubic austenite to the body-centered-tetragonal martensite result in a volumetric expansion, on cooling, of about 1 per cent (for a eutectoid steel) nonuniform stress patterns can be induced on transformation. As cooling starts at the surface, by the normal process of heat transfer, parts of a member can be expanding, because of transformation, while further inward normal contraction occurs on the cooling austenite. The danger of cracking and distortion (warping) as a consequence of the steep thermal gradients and the transformation involved in hardening steels can be eliminated by using good design and the selection of the proper alloys. Where section size, time factors, and alloy content (as it affects transformation curves) permit, improved practices by martempering shown by *EFGH* in Fig. 17.20, followed by tempering or austempering shown by *EFK*, may be feasible and are worthy of investigation for the particular alloy used.

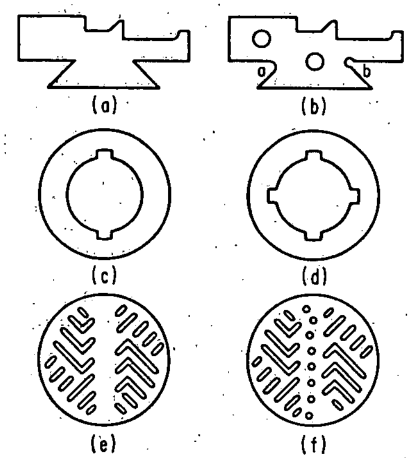

Fig. 17.22. Examples of good (*b*, *d*, and *f*) and bad (*a*, *c*, and *e*) designs for heat-treated parts.[8] (1) *b* is better than *a* because of fillets and more uniform mass distribution. (2) In *c*, cracks may form at keyways. (3) Warping may be more pronounced in *e* than in *f*, which are blanking dies.[8]

Uniform mass distribution, and the elimination of sharp corners (potential stress raisers) by the use of generous fillets, are recommended. Some design features pertinent to the elimination of quench cracks and the minimization of distortion by warping are illustrated by Fig. 17.22 in which *a*, *c*, and *e* represent poor designs in comparison with the suggested improvements apparent in *b*, *d*, and *f*.

Steels are tempered to relieve stresses, to impart ductility, and to produce a desirable microstructure by a reheating process of the quenched member. The tempering process is dependent on the temperature, time, and alloy content of the steel. Differ-

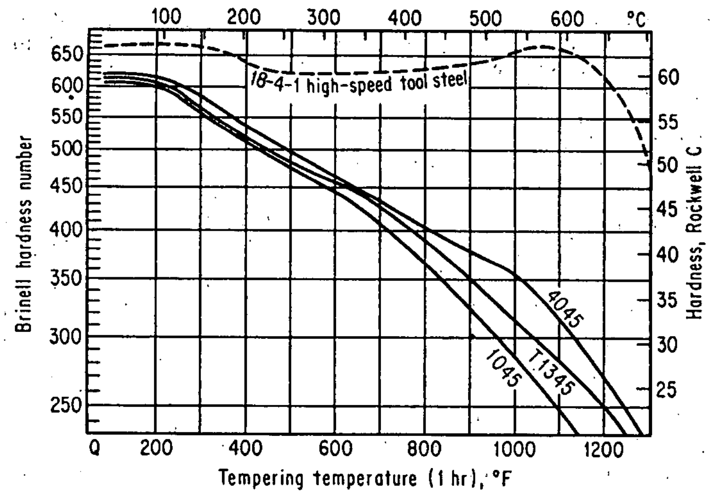

FIG. 17.23. Effect of tempering temperature on the hardnesses of SAE 1045, T1345, and 4045 steels. In the high-speed tool steel 18-4-1 secondary hardening occurs at about 1050°F.[9]

ent alloys soften at different rates according to the constitutionally dependent diffusional structure. The response to tempering for 1 hr for three different steels of the same carbon content is shown in Fig. 17.23. In addition, the tempering characteristics of a high-speed tool steel, 18 per cent W, 4 per cent Cr, 1 per cent V, and 0.9 per cent C, are shown to illustrate the secondary hardening at about 1050°F. The pronounced tendency for high-carbon steels to retain austenite on transformation normally has deleterious effects on dimensional stability and fatigue performance. In high-speed tool steel, the secondary hardening is due to the transformation of part of the retained austenite to newly transformed martensite. The structure contains tempered and untempered martensite with perhaps some retained austenite. Multiple tempering treatments on this type of steel produce a more uniform product.

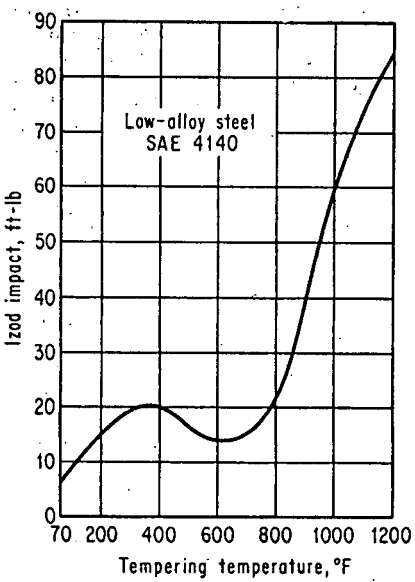

FIG. 17.24. In the tempering of this 4140 steel the notched-bar impact properties decrease in the range of 450 to 650°F.[9]

In low-alloy steels where the carbon content is above 0.25 per cent, there may be a tempering-temperature interval at about 450 to 650°F, during which the notch impact strength goes through a minimum. This is shown in Fig. 17.24 and is associated with the formation of an embrittling carbide network (ϵ carbide) about the martensite subgrain boundaries.

Tempering is therefore carried out up to 400°F where the parts are to be used principally for wear resistance, or in the range of 800 to 1100°F where greater toughness is required. In the nomenclature of structural steels, adopted by the Society of Automotive Engineers and the American Iron and Steel Institute, the first two numbers designate the type of steel according to the principal alloying elements and the last two numbers designate the carbon content:

Series designation	Types
10xx	Nonsulfurized carbon steels
11xx	Resulfurized carbon steels (free-machining)
12xx	Rephosphorized and resulfurized carbon steels (free-machining)
13xx	Manganese 1.75%
23xx*	Nickel 3.50%
25xx*	Nickel 5.00%
31xx	Nickel 1.25%, chromium 0.65%
33xx	Nickel 3.50%, chromium 1.55%
40xx	Molybdenum 0.20 or 0.25%
41xx	Chromium 0.50 or 0.95%, molybdenum 0.12 or 0.20%
43xx	Nickel 1.80%, chromium 0.50 or 0.80%, molybdenum 0.25%
44xx	Molybdenum 0.40%
45xx	Molybdenum 0.52%
46xx	Nickel 1.80%, molybdenum 0.25%
47xx	Nickel 1.05%, chromium 0.45%, molybdenum 0.20 or 0.35%
48xx	Nickel 3.50%, molybdenum 0.25%
50xx	Chromium 0.25, 0.40, or 0.50%
50xxx	Carbon 1.00%, chromium 0.50%
51xx	Chromium 0.80, 0.90, 0.95, or 1.00%
51xxx	Carbon 1.00%, chromium 1.05%
52xxx	Carbon 1.00%, chromium 1.45%
61xx	Chromium 0.60, 0.80, or 0.95%, vanadium 0.12%, 0.10% min, or 0.15% min
81xx	Nickel 0.30%, chromium 0.40%, molybdenum 0.12%
86xx	Nickel 0.55%, chromium 0.50%, molybdenum 0.20%
87xx	Nickel 0.55%, chromium 0.50%, molybdenum 0.25%
88xx	Nickel 0.55%, chromium 0.50%, molybdenum 0.35%
92xx	Manganese 0.85%, silicon 2.00%, chromium 0 or 0.35%
93xx	Nickel 3.25%, chromium 1.20%, molybdenum 0.12%
94xx	Nickel 0.45%, chromium 0.40%, molybdenum 0.12%
98xx	Nickel 1.00%, chromium 0.80%, molybdenum 0.25%

* Not included in the current list of standard steels.

The most probable properties of tempered martensite for low-alloy steels fall within narrow bands even though there are differences in sources and treatments. The relations for these shown in Fig. 17.25 are useful in predicting properties to within approximately 10 per cent.

Structural steels may be specified by hardenability requirements, the H designation, rather than stringent specification of the chemistry. Hardenability, determined by the standardized Jominy end-quench test, is a measurement related to the variation in hardness with mass, in quenched steels. Since different structures are formed as a function of the cooling rate and the transformation is affected by the nature of the alloying elements, it is necessary to know whether the particular steel is shallow (A) or deeply hardenable (C), as in Fig. 17.26. The hardenability of a particular steel is a useful criterion in selection because it is related to the mechanical properties pertinent to the section size.

The selection of through-hardened steel based upon carbon content is indicated below for some typical applications.

Carbon range	Requirement	Approx tensile strength level, psi	Applications
Medium, 0.3 to 0.5%	Strength and toughness	150,000	Shafts, bolts, forgings, nuts
Intermediate, 0.5 to 0.7%	Strength	225,000	Springs
High, 0.8 to 1.0%	Wear resistance	Greater than 300,000	Bearings, rollers, bushings

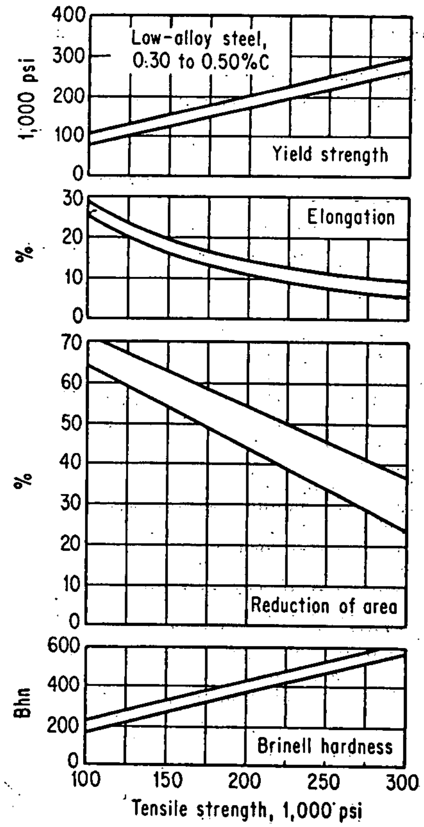

FIG. 17.25. The most probable properties of tempered martensite for a variety of low-alloy steels.[4]

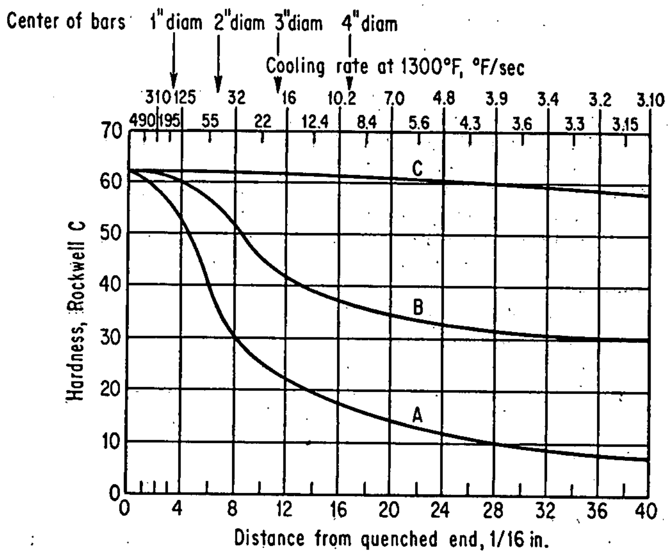

FIG. 17.26. Hardenability curves for different steels with the same carbon content.[7]

17.9. SURFACE-HARDENING TREATMENTS

The combination of high surface wear resistance and a tough-ductile core is particularly desirable in gears, shafts, and bearings. Various types of surface-hardening treatments and processes can achieve these characteristics in steels; the most important of these are the following:

Base metal	*Process*
Low C to 0.3%	Carburization—A carbon diffusion in the γ-phase region, with controlled hydrocarbon atmosphere or in a box filled with carbon. The case depth is dependent on temperature-time factors. Heat-treatment follows process
Medium C, 0.4 to 0.5%	Localized surface heating by induction or a controlled flame to above the Ac_3 temperature; quenched and tempered
Nitriding (Nitralloys, stainless steels)	Formation of nitrides (in heat-treated parts) in ammonia atmosphere at 950 to 1000°F, held for long times. A thin and very hard surface forms and there may be dimensional changes
Low C, 0.2%	Cyaniding—parts placed in molten salt baths at heat-treating temperatures; some limited carburization and nitriding occur for cases not exceeding 0.020 in. Parts are quenched and tempered.

The carbon penetration in carburization is determined by temperature-time-distance relations issuing from the solution of diffusional equations where D, the diffusion coefficient, is independent of concentrations. These relations, shown in Fig. 17.27, permit the selection of a treatment to provide specific case depths. Typical applications are as follows:

Case depth, in.	*Applications (automotive)*
More than 0.020	Push rods, light-load gears, water pump shafts
0.020–0.040	Valve rocker arms, steering-arm bushings, brake and clutch pedal shafts
0.040–0.060	Ring gears, transmission gears, piston pins, roller bearings
Greater than 0.060	Camshafts

The heat-treatments used on carburized parts depend upon grain-size requirements, minimization of retained austenite in the microstructure, amount of undissolved carbide network, and core-strength requirements. As a result of carburization, the surface fiber stresses are compressive. This leads to better fatigue properties. This treatment, which alters the surface chemistry by diffusion of up to 1 per cent carbon in a low-carbon steel, gives better wear resistance because the surface hardness is treated for values above 60 Rockwell C, while the low-carbon-content core has ductile properties to be capable of the transmission of torsional or bending loads.

Selection of the nitriding process requires careful consideration of cost because of the long times involved in the case formation. A very hard case having a hardness of about 70 Rockwell C ensures excellent wear resistance. Nitrided parts have good corrosion resistance and improved fatigue properties. Nitriding follows the finish

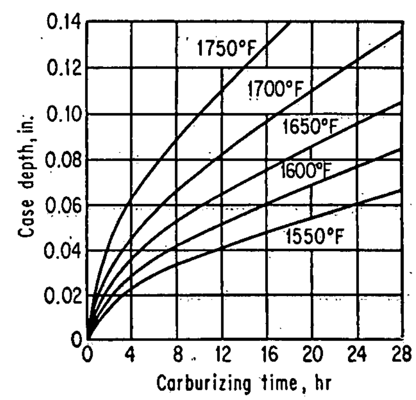

FIG. 17.27. Relation of time and temperature to carbon penetration in gas carburizing.[10]

machining and grinding operations, and many parts can be nitrided without great likelihood of distortion. Long service (several hundred hours) at 500°F has been attained in nitrided gears made from a chromium-base hot-work steel H11. Some typical nitrided steels and their applications are as follows:

Steel	Nitriding treatment		Case hardness, in.	Case depth Rockwell C	Applications
	Hr	°F			
4140	48	975	0.025–0.035	53–58	Gears, shafts, splines
4340	48	975	0.025–0.035	50–55	Gears, drive shafts
Nitralloy 135M	48	975	0.020–0.025	65–70	Valve stems, seals, dynamic faceplates
H11	70	960 + 980	0.015–0.020	67–72	High-temperature power gears, shafts, pistons

17.10. NOTCHED IMPACT PROPERTIES—CRITERIA FOR MATERIAL SELECTION

When materials are subject to high deformation rates and are particularly sensitive to stress concentrations at sharp notches, criteria must be established to indicate safe operating-temperature ranges. The impact test (Izod or Charpy V-notch) performed on notched specimens conducted over a prescribed temperature range indicates the likelihood of ductile (shear-type) or brittle (cleavage-type) failure. In this test the velocity of the striking head at the instant of impact is about 18 fps; so that the strain rates are several orders of magnitude greater than in a tensile test. The energy absorbed in fracturing a standard notched specimen is measured by the differences in potential energy from free fall of the hammer to the elevation after fracturing it. The typical effect of temperature upon impact energy for a metal which shows ductile and brittle characteristics is shown in Fig. 17.28. Interest centers on the transition temperature range and the material-sensitive factors such as composition, microstructure, and embrittling treatments. ASTM specifications for structural steel for ship plates specify a minimum impact energy at a given temperature, as, for example, 15 ft-lb at 40°F. It is desirable to use materials at impact energy levels and at service temperatures where crack propagation does not proceed. Some impact characteristics for construction steels are shown in Fig. 17.29.

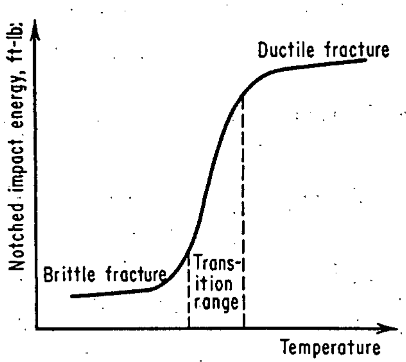

FIG. 17.28. The ductile-to-brittle transition in impact.

It is generally characteristic of pure metals which are face-centered cubic in lattice structure to possess toughness (have no brittle fracture tendencies) at very low temperatures. Body-centered-cubic pure metals, as well as hexagonal metals, do show ductile-to-brittle behavior. Tantalum, a body-centered-cubic metal, is a possible exception and is ductile in impact even at cryogenic temperatures. Alloyed metals do not follow any general pattern of behavior; some specific impact values for these are as follows:

Material	Charp V-notch at 80°F	Impact strength, ft-lb at −100°F
Cu-Be(2%) HT	5.4	5.5
Phosphor bronze (5% Sn):		
Annealed	167	193
Spring temper	46	44
Nilvar Fe-Ni (36%):		
Annealed	218	162
Hard	97	77
2024-T6 aluminum aircraft alloy, HT aged	12	12
7079-T6 aluminum aircraft alloy, HT aged	4.5	3.5
Mg-Al-Zn extruded	7.0	3.0

Austenitic stainless steels are ductile and do not exhibit transition in impact down to very low temperatures.

Some brittle service failures in steel structures have occurred in welded ships, gas-transmission pipes, pressure vessels, bridges, turbine generator rotors, and storage tanks. Serious consideration must then be given the effect of stress raisers, service temperatures, tempering embrittling structures in steels, grain-size effects, as well as the effects of minor impurity elements in materials.

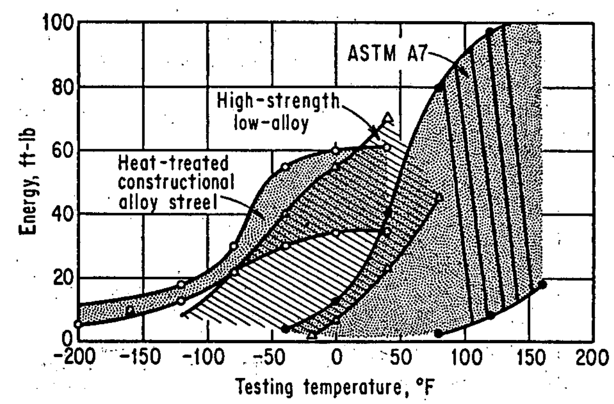

FIG. 17.29. Influence of testing temperature on notch toughness, comparing carbon steel of structural quality (ASTM A7) with high-strength low-alloy and heat-treated constructional alloy steel.[4] Charpy V-notch.

17.11. FATIGUE CHARACTERISTICS FOR MATERIALS SPECIFICATIONS

Most fatigue failures observed in service as well as under controlled laboratory tests are principally the result of poor design and machining practice. The introduction of potential stress raisers by inadequate fillets, sharp undercuts, and toolmarks at the surfaces of critically cyclically stressed parts may give rise to crack nucleation and propagation so that ultimate failure occurs. Particular attention should be given to material fatigue properties where rotating and vibrating members experience surface fibers under reversals of stress.

In a fatigue test, a highly polished round standard specimen is subjected to cyclic

loading; the number of stress reversals to failure is recorded. For sheets, the standard specimen is cantilever supported. Failure due to tensile stresses usually starts at the surface. Typical of a fatigue fracture is its conchoidal appearance, where there is a smooth region in which the severed sections rubbed against each other and where the crack progressed to a depth where the load could no longer be sustained. From the fatigue data a curve of stress vs. number of cycles to failure is plotted. Note that there can be considerable statistical fluctuation in the results (about ±15 per cent variations in stress).

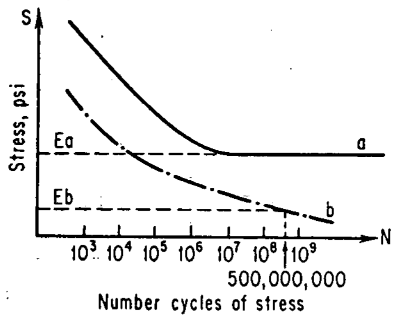

FIG. 17.30. Fatigue curves. (a) Most materials have an endurance limit E_a (asymptotic stress). (b) Endurance limit E_b (non-asymptotic) set at arbitrary value of N.

Two characteristics can be observed in fatigue curves with respect to the endurance limit shown by E_a and E_b in Fig. 17.30:

E_a, curve A, the asymptotic stress value, typical in most materials

E_b, curve B, a stress value taken at an arbitrary number of cycles; e.g., 500,000,000, typical in Al and Mg alloys

For design specifications, the endurance limit represents a safe working stress for fatigue. The endurance ratio is defined as the ratio of the endurance limit to the ultimate tensile strength. These values are strongly dependent upon the presence of notches on the surface and a corrosive environment, and on surface-hardening treatments. In corrosion, the pits formed act as stress raisers leading generally to greatly reduced endurance ratios. References 15 through 20 provide useful information on corrosion. A poorly machined surface or a rolled sheet with surface scratches evidences low endurance ratios, as do parts in service with sharp undercuts and insufficiently filleted changes in section.

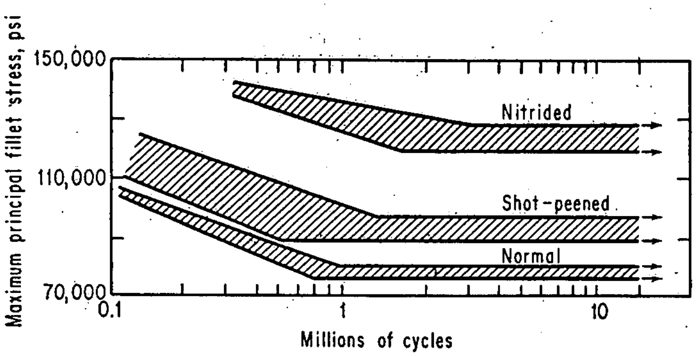

FIG. 17.31. Effects of surface-hardening treatments in improving the fatigue characteristics of a 4340 steel used as an aircraft crankshaft.[11]

Improvements in fatigue properties are brought about by those surface-hardening treatments which produce induced compressive stresses as in steels, nitrided (about 160,000 psi compressive stress) or carburized (about 35,000 psi compressive stress). An example of the effects of surface-hardening treatments on an aircraft crankshaft made from a 4340 hardened and tempered steel (30 Rockwell C) is shown in Fig. 17.31.

Metallurgical factors related to poorer fatigue properties are the presence of retained austenite in hardened steels, the presence of flakes or sharp inclusions in the

microstructure, and treatments which induce preferential corrosive grain-boundary attack. When parts are quenched or formed so that surface tensile stresses are present, stress-relieval treatments are advisable.

17.12. MATERIALS FOR HIGH-TEMPERATURE APPLICATIONS

(a) Introduction

Selection of materials to withstand stress at high temperature is based upon experimentally determined temperature stress-time properties. Some useful engineering design criteria follow.

1. Dimensional change, occurring by plastic flow, when metals are stressed at high temperatures for prolonged periods of time, as measured by creep tests
2. Stresses that lead to fracture, after certain set time periods, as determined by stress-rupture tests, where the stresses and deformation rates are higher than in a creep test
3. The effect of environmental exposure on the oxidation or scaling tendencies
4. Considerations of such properties as density, melting point, emissivity, ability to be coated and laminated, elastic modulus, and the temperature dependence on thermal conductivity and thermal expansion

Furthermore, the microstructural changes occurring in alloys used at high temperatures are correlated with property changes in order to account for the significant discontinuities which occur with exposure time. As a result of these evaluations, special alloys that have been (or are being) developed are recommended for use in different temperature ranges extending to about 2800°F (refractory range). Vacuum or electron-beam melting and special welding techniques are of special interest here in fabricating parts.

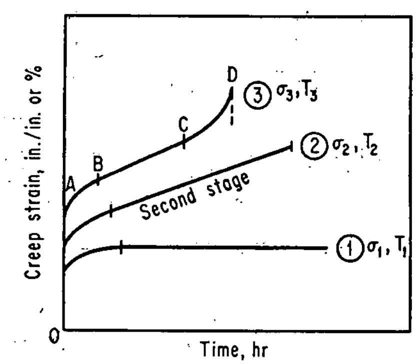

FIG. 17.32. Typical creep curves. At constant temperature, $\sigma_3 > \sigma_2 > \sigma_1$. At constant stress, $T_3 > T_2 > T_1$.

(b) Creep and Stress—Rupture Properties

In a creep test, the specimen is heated in a temperature-controlled furnace, an axial load is applied, and the deformation is recorded as a function of time, for periods of 1,000 to 3,000 hr. Typical changes in creep strain with time, for different conditions of stress and temperature, are shown in Fig. 17.32. Plastic flow creep, associated with the movement of dislocations by climb sliding of grain boundaries and the diffusion of vacancies, is characterized by:

1. OA, elastic extension on application of load
2. AB, first stage of creep with changing rate of creep strain
3. BC, second stage of creep, in which strain rate is linear and essentially constant
4. CD, third stage of increasing creep rate leading to fracture

Increasing stress at a constant temperature or increasing temperature at constant stress results in the transfers from the 1 to 2 to 3 curves in Fig. 17.32.

The engineering design considerations for dimensional stability are based upon

1. Stresses resulting in a second-stage creep rate of 0.0001 per cent per hour (1 per cent per 10,000 hr or 1 per cent per 1.1 years)
2. A second-stage creep rate of 0.00001 per cent per hour (1 per cent per 100,000 hr

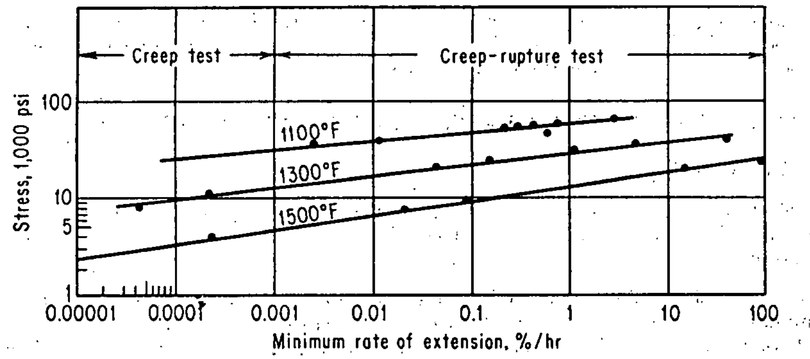

FIG. 17.33. Correlation of creep and rupture test data for type 316 stainless steel (18 Cr, 8 Ni, and Mo).[12]

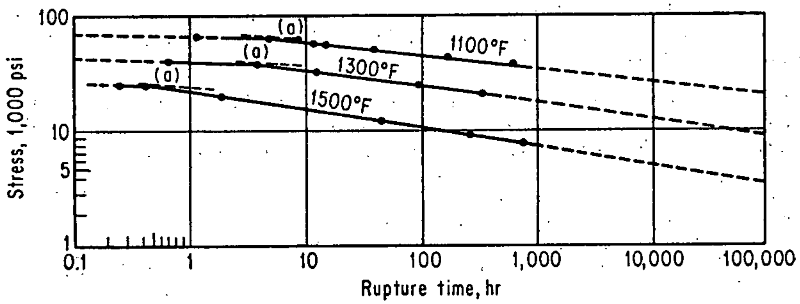

FIG. 17.34. Stress vs. rupture time for type 316 stainless steel.[12] The structural character associated with point (a), on each of the three relations, is that the mode of fracture changes from transgranular to intergranular.

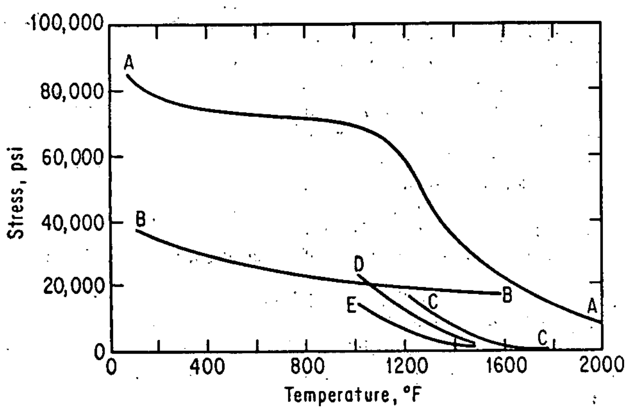

FIG. 17.35. Properties of type 316 stainless steel (18 Cr, 8 Ni, and Mo).[12]

A = short-time tensile strength
B = short-time yield strength, 0.2 per cent offset
C = stress for rupture 10,000 hr
D = stress for creep rate 0.0001 per cent per hr
E = stress for creep rate 0.00001 per cent per hr

or 1 per cent per 11 years), where weight is of secondary importance relative to long service life, as in stationary turbines

The time at which a stress can be sustained to failure is measured in a stress-rupture test and is normally reported as rupture values for 10, 100, 1,000, and 10,000 hr or more. Because of the higher stresses applied in stress-rupture tests, shown in Fig. 17.33, some extrapolation of data may be possible and some degree of uncertainty may ensue. Discontinuous changes at points *a* in the stress-rupture data shown in Fig. 17.34 are associated with a change from transgranular to intergranular fracture, and further microstructural changes can occur at increasing times. A composite picture of various high-temperature test results is given in Fig. 17.35 for a type 316 austenitic stainless steel.

(c) Material Selection

The aluminum and magnesium light alloys used in aircraft in their heat-treated condition have high-temperature applications limited to about 400°F. Low-density titanium alloys, of the alpha-beta heat-treatable type, have been used for aircraft gas-turbine compressor parts (where creep properties become important) in 600 to

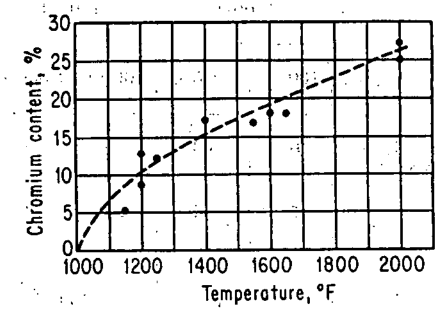

FIG. 17.36. The effect of chromium content on service temperature, without causing excessive sealing in alloys.[12]

1000°F applications. Low-alloyed steels are generally used safely to about 700°F in the high-temperature range. Above these temperatures, special alloys have been developed for the 1200 to 1800°F range and the 1800 to 2800°F range (the refractory alloys).

Alloys used in the temperature range of 1200 to 1800°F are essentially of the iron-, nickel-, and cobalt-base type and their structures, although predominantly of a single phase, may contain intermetallics and precipitating phases. Additions of chromium increase the oxidation resistance in a manner shown by Fig. 17.36. However, high-chromium alloys show depletion effects when used in a high vacuum. For nuclear applications, requiring low-neutron-absorption cross sections, alloys with high cobalt concentrations should be avoided. Some measured high-temperature stress-rupture properties for alloys used in this temperature range are listed in Table 17.3.

Applications of metals at the highest service temperatures call for the four refractory elements and their alloys. Each of these has a body-centered-cubic structure and a high melting point, oxidizes readily above 1200°F, and has the properties given in Table 17.4. The strength properties are affected by the impurities present (notably oxygen, carbon, and nitrogen), and therefore electron-beam melting under high vacuum is under investigation for attaining higher purities. Because of the oxidizing characteristics at high temperatures, protective coatings must be used.

Sheet products can be fabricated from Ta, Cb, and Mo by conventional means, since they have reasonably good ductilities at room temperature. However, tungsten is relatively brittle at room temperature and for this reason sheet-fabrication methods

Table 17.3. High-temperature Rupture Strength Properties for Some Superalloys[13]

Alloy	Principal alloy content, %	Rupture strengths, 1,000 psi				Typical applications
		1200°F		1500°F		
Fe base		100 hr	1,000 hr	100 hr	1,000 hr	
Incaloy 901	13 Cr; 43 Ni; 34 Fe, and Mo and Ti	94	78	24	15	Gas-turbine rotor disks
Refractory 26	18 Cr; 38 Ni; 20 Co, bal. Fe, and Mo and Ti	80	63	27	18	Gas-turbine parts, blading, bolting
		1200°F		1500°F		
Co base		100 hr	1,000 hr	100 hr	1,000 hr	
S816	20 Cr; 20 Ni; bal. Co and W and Mo and Cb and Fe	60	46	25	18	Jet-engine buckets
HS25	20 Cr; 10 Ni; 15 W, bal. Co	70	54	24	17	Jet-engine parts, sheet alloy
		1500°F		1800°F		
Ni base		100 hr	1,000 hr	100 hr	1,000 hr	
Inconel 713C	11.5 Cr; 74 Ni; Al and Mo and Cb	68	47	20	15	Jet-engine blades
Hastelloy R235	15.5 Cr; 10 Fe bal. Ni and Mo and Ti	40	30	8	5	Gas-turbine Jet-engine parts, sheet
Rene 41	19 Cr; 11 Co; 10 Mo; bal. Ni	45	29	11	...	Gas turbine, sheet, bolting

Table 17.4. Properties of Refractory Elements

Element	Melting point, °F	Density, lb cu in.	Recrystallization temp., °F	Young's modulus of elasticity at room temp., E, psi
Columbium, Cb........	4379	0.31	1785–2100	30,000,000
Molybdenum, Mo......	4730	0.369	2100–2200	47,000,000
Tantalum, Ta..........	5425	0.60	2200–2400	27,000,000
Tungsten, W..........	6170	0.697	2200–3000	50,000,000

require special development. Joining by fusion welding results in ductile joints for Ta and Cb, whereas for W and Mo grain-coarsening and cracking tendencies are factors of importance in attaining usable products.

High-temperature strength properties are substantially improved by alloying additions to the refractory elements. Tungsten-base alloys, some in the development stage, are used at the highest temperatures. Some typical rupture strength properties determined in heats are given in Table 17.5.

Table 17.5. Rupture Strength Properties[13]

Metal	Nominal alloy content, %	Rupture strength, 1,000 psi	
		2000°F	
Cb base FS82...........	33 Ta, 7.5 Zr	10 hr	100 hr
		25	18
Mo base................	0.5 Ti	2000°F, 100 hr	2400°F, 100 hr
		34	10
		2500°F	
W base................	2% ThO_2	10 hr	100 hr
		29	22

17.13. MATERIALS FOR LOW-TEMPERATURE APPLICATION

Materials for low-temperature application are of increasing importance because of the technological advances in cryogenics. The most important mechanical properties are usually strength and stiffness, which generally increase as the temperature is decreased. The temperature dependence on ductility is a particularly important criterion in design, because some materials exhibit a transition from ductile to brittle behavior with decreasing temperature. Factors related to this transition are microstructure, stress concentrations present in notches, and the effects of rapidly applied strain rates in materials. Mechanical design can also influence the tendency for brittle failure at low temperature, and for this reason, it is essential that sharp notches (which can result from surface-finishing operations) be eliminated and that corners at changes of section be adequately filleted.

Low-temperature tests on metals are made by measuring the tensile and fatigue properties on unnotched and notched specimens and the notched impact strength. Metals exhibiting brittle characteristics at room temperature, by having low values of per cent elongation and per cent reduction in area in a tensile test as well as low impact strength, can be expected to be brittle at low temperatures also. Magnesium alloys, some high-strength aluminum alloys in the heat-treated condition, copper-beryllium heat-treated alloys, and tungsten and its alloys all exhibit this behavior. At best, applications of these at low temperatures can be made only provided that they adequately fulfill design requirements at room temperature.

When metals exhibit transitions in ductile-to-brittle behavior, low-temperature applications should be limited to the ductile region, or where experience based on field tests is reliable, a minimum value of impact strength should be specified. The failure,

by breaking in two, of 19 out of 250 welded transport ships in World War II, caused by the brittleness of ship plates at ambient temperatures, focused considerable attention on this property. It was further revealed in tests that these materials had Charpy V-notch impact strengths of about 11 ft-lb at this temperature. Design specifications for applications of these materials are now based on higher impact values. For temperatures extending from subatmospheric temperatures to liquid-nitrogen temperatures (−320°F), transitions are reported for ferritic and martensitic steels, cast steels, some titanium alloys, and some copper alloys.

Design for low-temperature applications of metals need not be particularly concerned with the Charpy V-notch impact values provided they can sustain some shear deformation and that tensile or torsion loads are slowly applied. Many parts are used successfully in polar regions, being based on material design considerations within the elastic limit. When severe service requirements are expected in use, relative to rapid rates of applied strain on notch-sensitive metals, particular attention is placed on selecting materials which have transition temperatures below that of the environment.

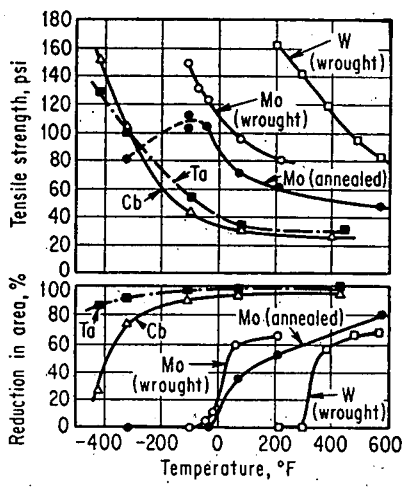

Fig. 17.37. Strength and ductility of refractory metals at low temperatures.[13]

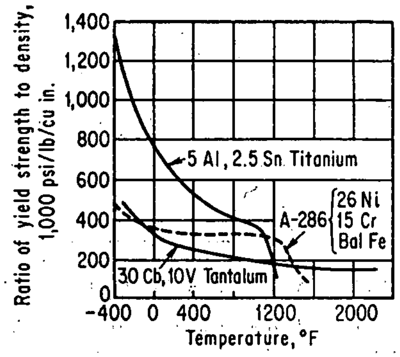

Fig. 17.38. Yield-strength-to-density ratios related to temperature for some alloys of interest in cryogenic applications.[13]

Some important factors related to the ductile-to-brittle transition in impact are the composition, microstructure, and changes occurring by heat-treatment, preferred directions of grain orientation, grain size, and surface condition.

The transition temperatures in steels are generally raised by increasing carbon content, by the presence of more than 0.05 per cent sulfur, and significantly by phosphorus at a rate of 13°F per 0.01 per cent P. Manganese up to 1.5 per cent decreases the transition temperature and high nickel additions are effective, so that in the austenitic stainless steels the behavior is ductile down to liquid-nitrogen temperatures. In high-strength medium-alloy steels it is desirable, from the standpoint of lowering the transition range, that the structure be composed of a uniformly tempered martensite, rather than containing mixed products of martensite and bainite or martensite and pearlite. This can be controlled by heat-treatment. The preferred orientation that can be induced in rolled and forged metals can affect notched impact properties; so that specimens made from the longitudinal or rolling direction have higher impact strengths than those taken from the transverse direction. Transgranular fracture is normally characteristic of low-temperature behavior of metals. The metallurgical factors leading to intergranular fracture, due to the segregation of

Table 17.6. Test Properties

Tensile Test Properties

Material	Tensile strength, 1,000 psi		Yield strength, 1,000 psi		Elongation, %		Modulus of elasticity, 100 psi	
	80°F	−100°F	80°F	−100°F	80°F	−100°F	80°F	−100°F
Beryllium copper 2% Be—heat-treated sheet...	189	194	154	170	3	3	19.1	19.1
Phosphor bronze 5% Sn; spring temp..........	98	107	90	97	7	11	16.5	17.1
Molybdenum sheet partly recrystallized..........	97	141	75	130	19	3.5	48.7	47.5
Tungsten wire, drawn....	214	...	196	...	2.6	....	56	
Tantalum sheet, annealed	55	71	36	66	27	25	28.2	28.3
Nilvar sheet 36 Ni; 74 Fe, rolled..............	76	101	62	76	27	30	21.8	19.7

Sheet Fatigue Properties

Material	Fatigue strength at 2 × 10⁷ cycles 1,000 psi		Endurance ratios	
	80°F	−100°F	80°F	−100°F
Beryllium copper..............	31	45	0.16	0.23
Molybdenum....................	46	65	0.59	0.47
Tantalum......................	35	41	0.64	0.58
Nilvar........................	26	30	0.33	0.30

Charpy V-notch Impact Strength

Material	Impact strength, ft-lb	
	80°F	−100°F
Beryllium copper...............	5.4	5.4
Phosphor bronze................	46	44
Nilvar.........................	97	77

embrittling constituents at grain boundaries, cause concern in design for low-temperature applications. In addition to the control of these factors for enhanced low-temperature use, it is important to minimize or eliminate notch-producing effects and stress concentration, by specifying proper fabrication methods and providing adequate controls on these, as by surface inspection.

Examples of some low-temperature properties of the refractory metals, all of which have body-centered-cubic structures, are shown in Fig. 17.37. The high ductility of tantalum at very low temperatures is a distinctive feature in this class that makes it attractive for use as a cryogenic (as well as a high-temperature) material. Based on the increase of yield-strength-to-density ratio with decreasing temperatures shown in Fig. 17.38, the three alloys of a titanium-base Al (5) Sn (2.5), an austenitic iron-base Ni (26), Cr (15) alloy A286, as well as the tantalum-base Cb (30), 10 V alloy, are also useful for cryogenic use.

Comparisons of the magnitude of property changes obtained by testing at room temperature and −100°F for some materials of commercial interest are shown in Table 17.6.

17.14. RADIATION DAMAGE[31]

A close relationship exists between the structure and the properties of materials Modification and control of these properties are available through the use of various metallurgical processes, among them the concept of nuclear radiation. Nuclear radiation is a process whereby an atomic nucleus undergoes a change in its properties brought about by interatomic collisions.

The energy transfer which occurs when neutrons enter a metal may be estimated by simple mechanics, the quantity of energy transferred being dependent upon the atomic mass. The initial atomic collision, or primary "knock-on" as it is called, has enough energy to displace approximately 1,000 further atoms, or so-called secondary knock-ons. Each primary or secondary knock-on must leave behind it a resulting vacancy in the lattice. The primaries make very frequent collisions because of their slower movement, and the faster neutrons produce clusters of "damage," in the order of 100 to 1,000 angstroms in size, which are well separated from one another.

Several uncertainties exist about these clusters of damage, and because of this it is more logical to speak of radiation damage than of point defects, although much of the damage in metals consists of point defects. Aside from displacement collisions, replacement collisions are also possible in which moving atoms replace lattice atoms. The latter type of collision consumes less energy than the former.

Another effect, important to the life of the material, is that of transmutation, or the conversion of one element into another. Due to the behavior of complex alloys, the cumulative effect of transmutation over long periods of time will quite often be of importance. U^{235}, the outstanding example of this phenomenon, has enough energy after the capture of a slow neutron to displace one or more atoms.

Moving charged particles may also donate energy to the valence electrons. In metals this energy degenerates into heat, while in nonconductors the electrons remain in excited states, and will sometimes produce changes in properties.

Figure 17.39 illustrates the effect of irradiation on the stress-strain curve of iron crystals at various temperatures.[32] In metals other than iron irradiation tends to produce a ferrous-type yield point and has the effect of hardening a metal. This hardening may be classified as a friction force and a locking force on the dislocations. Some factors of irradiation hardening are:

1. It differs from the usual alloy hardening in that it is less marked in cold-worked than annealed metals.
2. Annealing at intermediate temperatures may increase the hardening.
3. Alloys may exhibit additional effects, due for example to accelerated phase changes and aging.

The most noticeable effect of irradiation is the rise in transition temperatures of metals which are susceptible to cold brittleness. Yet another consequence of irradiation is the development of internal cracks produced by growth stresses. At high enough temperatures gas atoms can be diffused and may set up large pressures within the cracks.

Some other effects of irradiation are swelling, phase changes which may result in greater stability, radiation growth, and creep. The reader is referred to ref. 31 for an analysis of these phenomena.

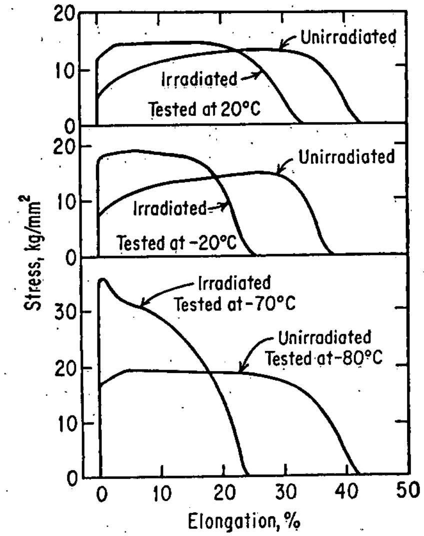

Fig. 17.39. Effect of irradiation on stress-strain curves of Fe single crystals tested at different temperatures. Irradiation dose 8×10^{17} thermal n/cm². (*Courtesy of ref. 31.*)

17.15. PRACTICAL REFERENCE DATA

Table 17.7 through 17.10 give various properties of commonly used materials. Figure 17.40 provides a hardness conversion graph for steel. References 21 through 30 yield more information.

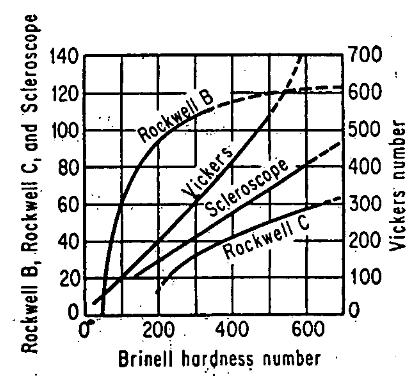

Fig. 17.40. Hardness conversion curves for steel.

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